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MEMORANDUM

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Date: March 27, 1996

cc: Ron Frehner

From: Peter Vagt

Subject: Transmittal Letter
Past Modeling Reports
ACS NPL Site

During the conference call on March 27, 1996, U.S. EPA requested further information regarding the groundwater modeling that has been conducted for the ACS NPL Site.

Three documents are attached.

- **Appendix Y from the Baseline Risk Assessment.** It was part of the Remedial Investigation Report. It reports the implementation of the original groundwater model.

- **Appendix A-2. Groundwater Model.** This modeling used the basic model set up for the Risk Assessment to evaluate the groundwater extraction trench originally proposed in 1995.

- **Appendix A-1. Pumping Test.** This is a report on the pumping test conducted at the ACS site in March 1995. It is referenced in Appendix A-1

Please do not hesitate to call me if I can provide clarification.

PJV
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APPENDIX A. AQUIFER PROPERTY ANALYSIS

Appendix A-1. Pumping Test

A pumping test was conducted at the ACS NPL Site on March 20 and 21, 1995 to evaluate the hydraulic characteristics of the unconfined aquifer. The pumping test data was used in conjunction with the existing site data to provide aquifer information for the design of the Groundwater Containment System (PGCS).

The scope of the pumping test included:

- Installing and developing a 6-inch diameter PVC extraction well with fully penetrating well screen.
- Installing two piezometers as observation wells.
- Conducting a step test to establish potential well capacity.
- Establish a baseline of background aquifer variability by instrumenting two on-site wells to monitor water level information for a period preceding, during, and after the pumping test.
- Conducting a 24-hour pumping test and recording water levels in five observation wells (besides the two baseline wells).
- Measuring recovery of the water levels in the observation wells for 39 hours following the pumping test.
- Normalizing the drawdown data to account for independent water level variability during the pumping test.
- Performing data analysis and interpretation for the pumping test data.

The pumping test was set up and operated in accordance with the approved plan, as detailed in Appendix A of the PGCS RD/RA Work Plan. Figure 1 shows the locations of the test well (EW-01) and the observation wells used to collect data for the pumping test. The extraction well and the observation wells were constructed in accordance with Montgomery Watson Standard Operating Procedures (SOPs) which were included in Appendices B and C of the PGCS RD/RA Work Plan.

Two piezometers were constructed for the pumping test. In addition, two existing piezometers and one existing monitoring well were used during the pumping test. Water level data was recorded at the following locations during the pumping test:

Observation Point	Distance from EW01	Aquifer Measured
P51	10 feet	Screened across the water table in the upper aquifer
P50	25 feet	Screened across the water table in the upper aquifer
P38	60 feet	Screened across the water table in the upper aquifer
P27	230 feet	Screened across the water table in the upper aquifer
MW9	230 feet	Ten-foot screen in the upper portion of the lower, confined aquifer
MW13	1,000 feet	Ten-foot screen across the water table, recording baseline water levels.
MW10	1,000 feet	Ten-foot screen in the upper portion of the lower confined aquifer, recording baseline water levels.

FIELD METHODS

Baseline Data Recording

A baseline data collection system was set up and monitored on site, starting four days before initiation of the 24 hour pumping test. Recorded data included:

Aquifer Water Level Data. Monitoring wells MW13 (upper aquifer) and MW10 (lower aquifer were instrumented with data loggers. Water levels were recorded at 15 minute intervals, beginning at 5:45 PM on March 16, 1995 and continued until 8:00 AM on March 23, 1995, 39 hours after conclusion of the extraction phase of the pumping test. (Test Data confirmed, that these wells were beyond the influence of the pumping test extraction.)

Precipitation. Total on-site precipitation for the background period was recorded prior to starting the pumping test at 8:00 AM on March 20, 1995. A major rainfall occurred 12 hours before the pumping test was started. No precipitation fell during the pumping test.

Barometric Pressure. Barometric pressure was recorded prior to initiation of the pumping test and at the conclusion of the pumping test. No corrections were necessary.

PUMPING TEST

Step Test

The step test was conducted immediately following the development of the extraction well, EW01. The observation wells were not instrumented with data loggers during this phase.

The step test was conducted to evaluate the capacity of the extraction well and the aquifer, so that an appropriate extraction rate could be used for the pumping test. There were three steps to the test.

Step	Pumping Rate	Duration	Drawdown
1	4 gpm	15 minutes	8 feet
2	5 gpm	5 minutes	Well de-watered
3	3 gpm	35 minutes	6 feet

The total saturated thickness of the water table aquifer was 12.8 feet. It was determined that the sustainable pumping rate for the 24 hour pumping test would be on the order of 1 to 2 gpm.

24-Hour Pumping Test

The pumping test was initiated at 5:10 PM on March 20, 1995. The drawdown portion of the test continued for 24 hours (1,440 minutes). Data logging was re-set and continued for another 1.6 days (2,355 minutes) after extraction was stopped.

The pumping test started with a pumping rate of 2 gpm. After 50 minutes, drawdown was observed to be more than half the available saturated thickness of the aquifer, so the pumping rate was decreased to 1 gpm. The pumping rate was further reduced to 0.75 gpm 750 minutes into the test, and to 0.60 gpm at 920 minutes. The following table shows total volume of groundwater extracted during the 24 hour test.

Time (min)	Elapsed Time (min)	Q (gpm)	Gallons
0			
50	50	2.0	100
750	700	1.0	700
920	170	0.75	128
1440	520	0.6	312
		Total Q:	1240
		Average GPM:	0.86

In accordance with the Work Plan, samples of the groundwater were collected for laboratory analysis during the pumping test. The results were utilized in the Remedial Design (RD) and are included in the RD technical memorandum.

PUMPING TEST DATA ANALYSIS

Normalization of Drawdown Data

Approximately 12 hours prior to initiation of the pumping test, approximately 1 inch of precipitation fell at the site. The background water levels measured in MW13 showed the immediate effect and recession curve from the recharge (Figure 2). The data was normalized by subtracting the change in background water for each time period from the recorded drawdown values for each observation well during the pumping test. The corrected data is tabulated at the end of this appendix. The normalized data was used to perform all analyses.

Drawdown Analysis
The three piezometers located within 60 feet of the extraction well exhibited drawdown in response to the pumping test. At greater distances there were no effects other than those accounted for by baseline water level variability.

The data for the three piezometers, P51 located 10 feet from EW01, P50 located 25 feet from EW01 and P38 located 60 feet from EW01 were evaluated by three methods. The AqteSolve software package was used to conduct the Theis Time-Drawdown analysis for each observation well. AqteSolve was also used to evaluate the data for observation well P51 by the Theis Recovery Method. The data was evaluated by graphic methods, using the Distance-Drawdown Method.

Plots of each of the data are provided for each of the observation wells on the following pages. Plots produced by the AqteSolve software list the basic assumptions that were used in the calculations. These include the discharge rate (Q), the distance from the extraction well (r), and the saturated thickness of the aquifer (b). The results are reported in Transmissivity (T), which is the hydraulic conductivity (k) multiplied by the aquifer thickness (b).

The results of the data evaluation are summarized in Table 1. The calculated values for the hydraulic conductivity of the aquifer ranged from 1.8×10^{-3} to 1.8×10^{-2} cm/sec. The average hydraulic conductivity value was 6.3×10^{-3} cm/sec. Values of storativity were calculated to in the range of 10^{-2} (unitless). A 24 hour pumping test was of too short duration to separate out the effects of delayed yield. More likely values for the specific yield are 0.1 to 0.3 (unitless), which is typical for an unconfined sand aquifer.

Assumptions
Pumping test analyses are based on analytical equations that relate pumping rate and drawdown to hydraulic properties of the aquifer under ideal conditions. The ideal conditions include:

1. The aquifer is of infinite areal extent.
2. The aquifer is homogeneous, isotropic, and of uniform thickness.
3. Prior to pumping, the piezometric surface is horizontal.
4. The aquifer is pumped at a constant discharge rate.
5. The aquifer is assumed to be confined.
6. The pumped well penetrates the entire aquifer and thus receives water from the entire aquifer by horizontal flow.
7. The diameter of the well is small so the storage effects of the well can be neglected.
8. Water removed from storage is discharge instantaneously with decline in head.

Conditions for pumping tests are generally less than ideal. Therefore the analysis and interpretation of the results take into account the limitations of the data and the potential effects that the inability to meet ideal conditions have on the estimates of the hydraulic properties. For the purposes of this pumping test, assumptions 1, 2, 3, 7, and 8 were assumed to exist over the time of the pumping test for the area of the aquifer affected. The other assumptions were not met and therefore precision of the test is limited.

- The pumping rate was variable over the time of the test, so Assumption 4 was not met. The average discharge rate of 0.86 gpm was rounded to one significant figure and 1 gpm was used in conducting the analysis. "Rounding-up" the discharge rate may have the effect of slightly over-estimating the hydraulic conductivity value.

- The aquifer is a water table aquifer and is not confined (Assumption 5). However, since the pumping test was of relatively short duration (by design), the available analytical methods required an evaluation assuming confined conditions. Therefore, the values calculated for S, may be representative of the instantaneous de-pressurizing of the aquifer (storativity), rather than "specific yield," the storage coefficient for unconfined conditions.

- Because the aquifer is not confined, the saturated thickness at the point of extraction was reduced to less than the full 12.8 foot saturated thickness of the aquifer. As a result, groundwater flow was both vertical and horizontal in the vicinity of the pumping well and the conditions of Assumption 6 were not met. The result would be an apparent reduction in hydraulic conductivity because of the required convergence of flow. The result would be an under-estimate of the hydraulic conductivity.

- Because of the low pumping rate, the total volume of water stored in the well makes up a significant portion of the groundwater extracted during the pumping test. As a result the storativitity value calculated for the aquifer is likely to be non-representative (Assumption 8).

Several factors are also apparent in the plots of the data.

- The drawdown curves for each of the observation wells flatten out and depart from the ideal Theis curve. (See plot for Well P51). It is likely that "leakage" is occurring in the form of delayed yield.

- The distance drawdown plots indicate that r_o is approximately 60 feet. This sugests that observation well P38, located 60 feet from EW01 the extraction well, is right at the edge of the zone of influence for the pumping test.

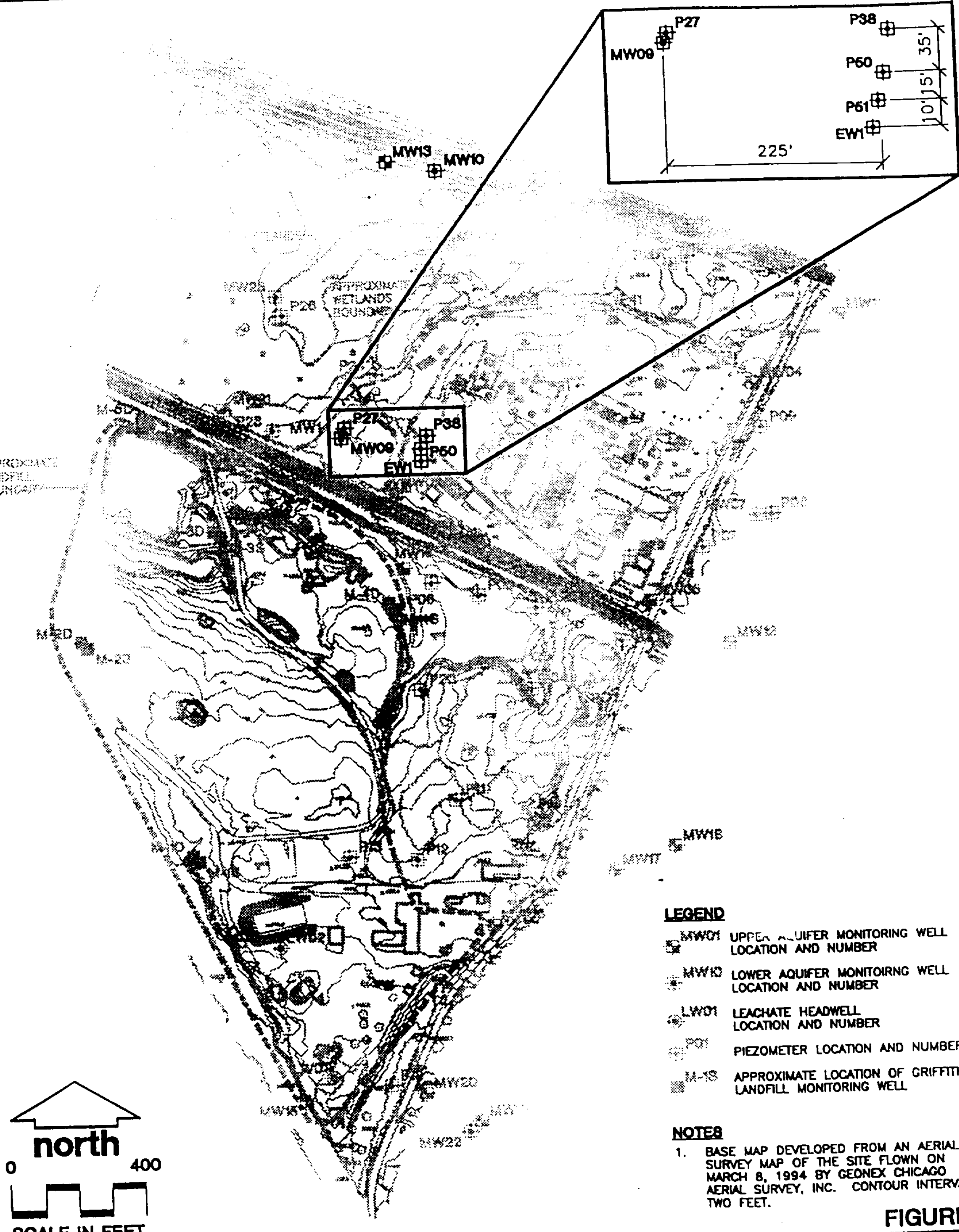
Attachments

Figure 1. Pumping Test Extraction and Observation Well Layout
Figure 2. Baseline Water Levels - MW13
Table 1. Results of Pumping Test Analysis
AqteSolve Time-Drawdown Results -- Data Curves and Calculations
Distance-Drawdown Results -- Calculations and Data Curves
Listing of Corrected Normalized Data

PJV
APPEND-A.DOC
4077.0050

Table 1. Results of Pumping Test Analysis

Wells	Distance	Specific Yield	Transmissivity ft*ft/min	Hydraulic Conductivity (ft/min)	Hydraulic Conductivity (cm/sec)	Evaluaton Method
P51	10	0.034	0.0461	3.6E-3	1.8E-3	Theis
		0.015	0.1405	1.1E-2	5.6E-3	Theis
		na	0.0987	7.7E-3	3.9E-3	Theis Recovery
P50	25	0.012	0.1784	1.4E-2	7.1E-3	Theis
P38	60	0.018	0.4608	3.6E-2	1.8E-2	Theis
	Time					
All	400 min	0.364		8.3E-3	4.2E-3	Jacob Distance/Drawdown
	800 min	0.745		6.8E-3	3.5E-3	Jacob Distance/Drawdown
	1440 min					
				Average Value:	6.3E-3	
				Geometric Mean:	5.0E-3	
				Minimum:	1.8E-3	
				Maximum:	1.8E-2	



LEGEND

- MW01 UPPER AQUIFER MONITORING WELL LOCATION AND NUMBER
- MW10 LOWER AQUIFER MONITOIRNG WELL LOCATION AND NUMBER
- LW01 LEACHATE HEADWELL LOCATION AND NUMBER
- P01 PIEZOMETER LOCATION AND NUMBER
- M-1S APPROXIMATE LOCATION OF GRIFFITH LANDFILL MONITORING WELL

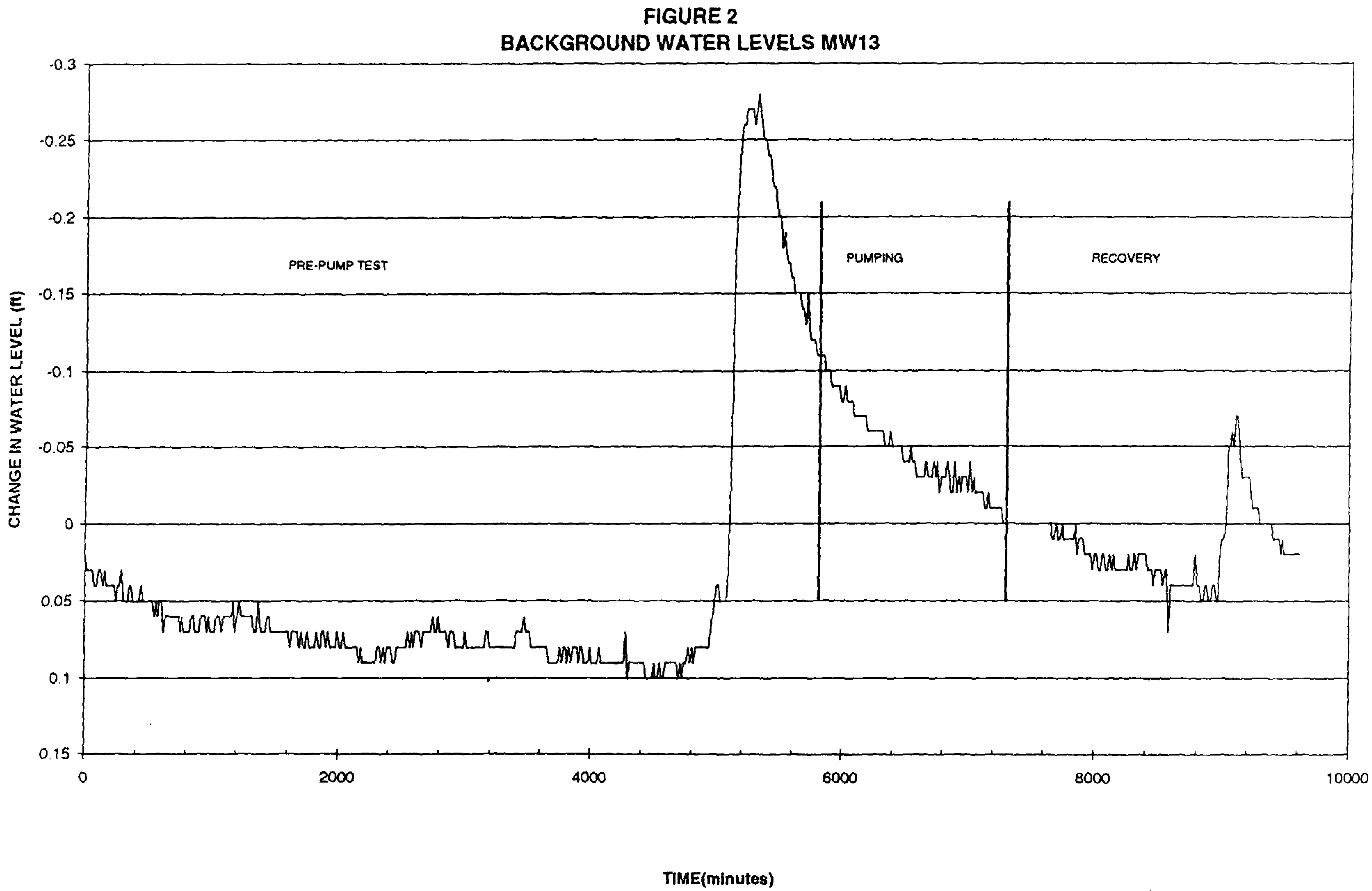
NOTES

1. BASE MAP DEVELOPED FROM AN AERIAL SURVEY MAP OF THE SITE FLOWN ON MARCH 8, 1994 BY GEONEX CHICAGO AERIAL SURVEY, INC. CONTOUR INTERVAL TWO FEET.

FIGURE A1

Developed By DAP — Drawn By DLF	PUMP TEST WELL CONFIGURATION MAP	Drawing Number 4077.0030 **A66**
Approved By — Date	PUMP TEST TECH-MEMO AMERICAN CHEMICAL SERVICE, INC. NPL SITE GRIFFITH, INDIANA	**MONTGOMERY WATSON**
Reference		
Revisions		

QUALITY CONTROL: Graphic Standards / Lead Professional; Technical Review / Project Manager; Management Review / Other



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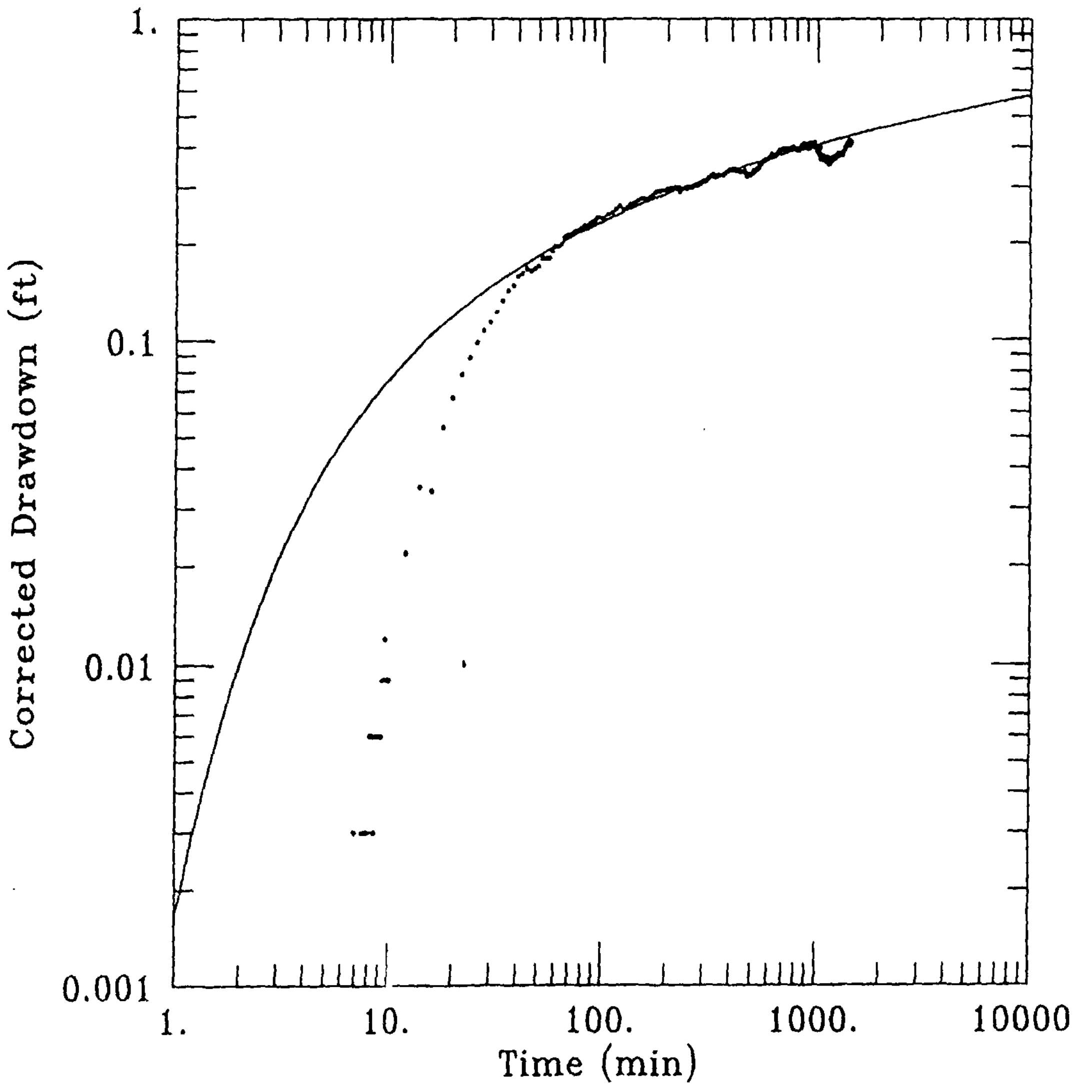
Client: ACS PRP GROUP	Company: ...TGOMERY WATSON
Location: GRIFFITH, INDIANA	Project: 4077.0040

WELL P51 CORRECTED DRAWDOWN



DATA SET:
P51CORR.DAT
04/11/95

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Theis

PROJECT DATA:
test date: MARCH 20-21, 1995
test well: EW1
obs. well: P51

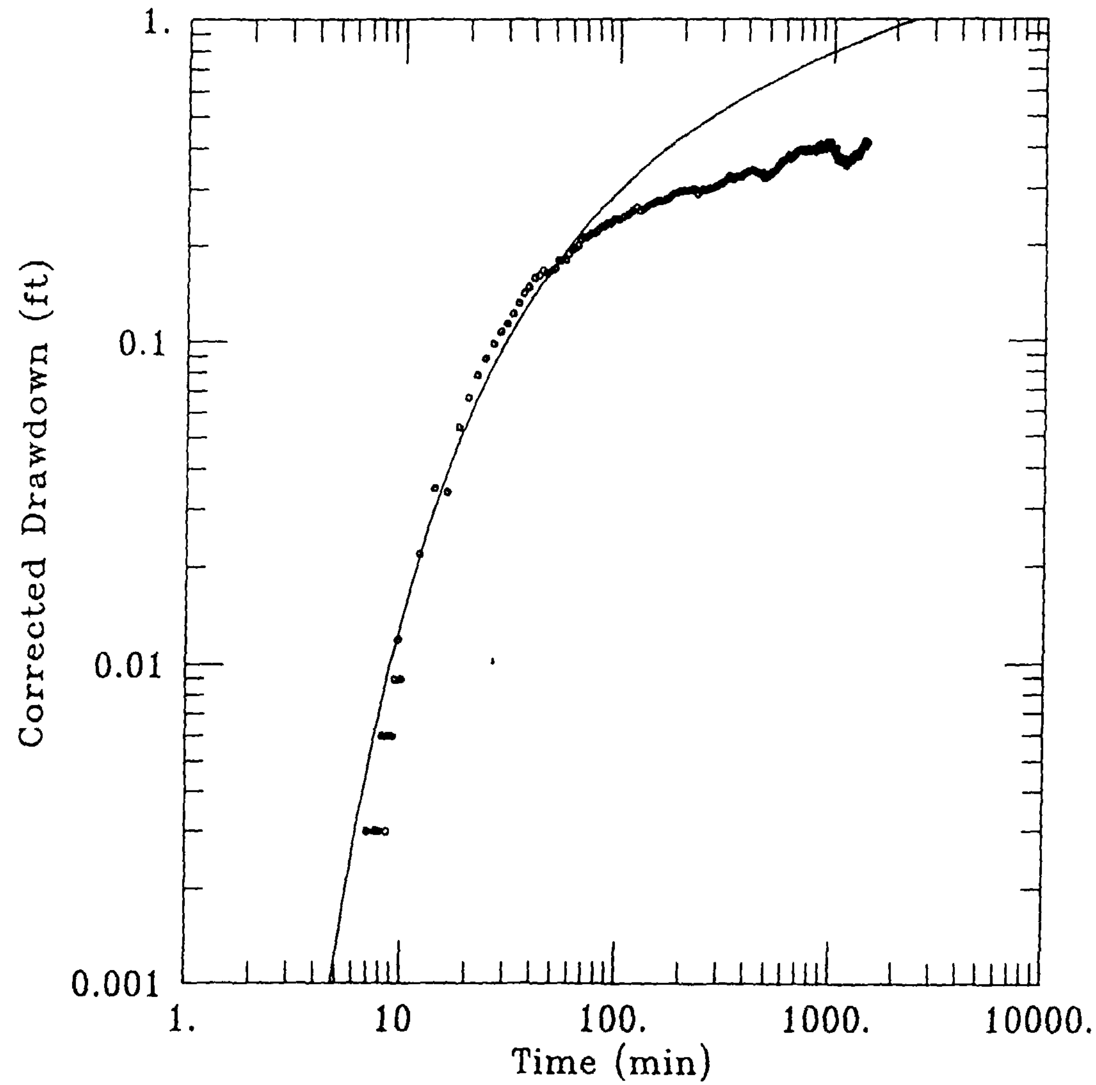
TEST DATA:
Q = 1. gal/min
r = 10. ft
r_c = 0.25 ft
r_w = 0.6 ft
b = 12.8 ft

PARAMETER ESTIMATES:
T = 0.1405 ft^2/min
S = 0.01473

AQTESOLV

Client: ACS PRP GROUP	Company: MONTGOMERY WATSON
Location: GRIFFITH, INDIANA	Project: 4077.0040

WELL P51 CORRECTED DRAWDOWN



DATA SET:
P51CORR.DAT
04/11/95

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Theis

PROJECT DATA:
test date: MARCH 20-21, 1995
test well: EW1
obs. well: P51

TEST DATA:
Q = 1. gal/min
r = 10. ft
r_c = 0.25 ft
r_w = 0.6 ft
b = 12.8 ft

PARAMETER ESTIMATES:
T = 0.0461 ft^2/min
S = 0.0342

AQTESOLV

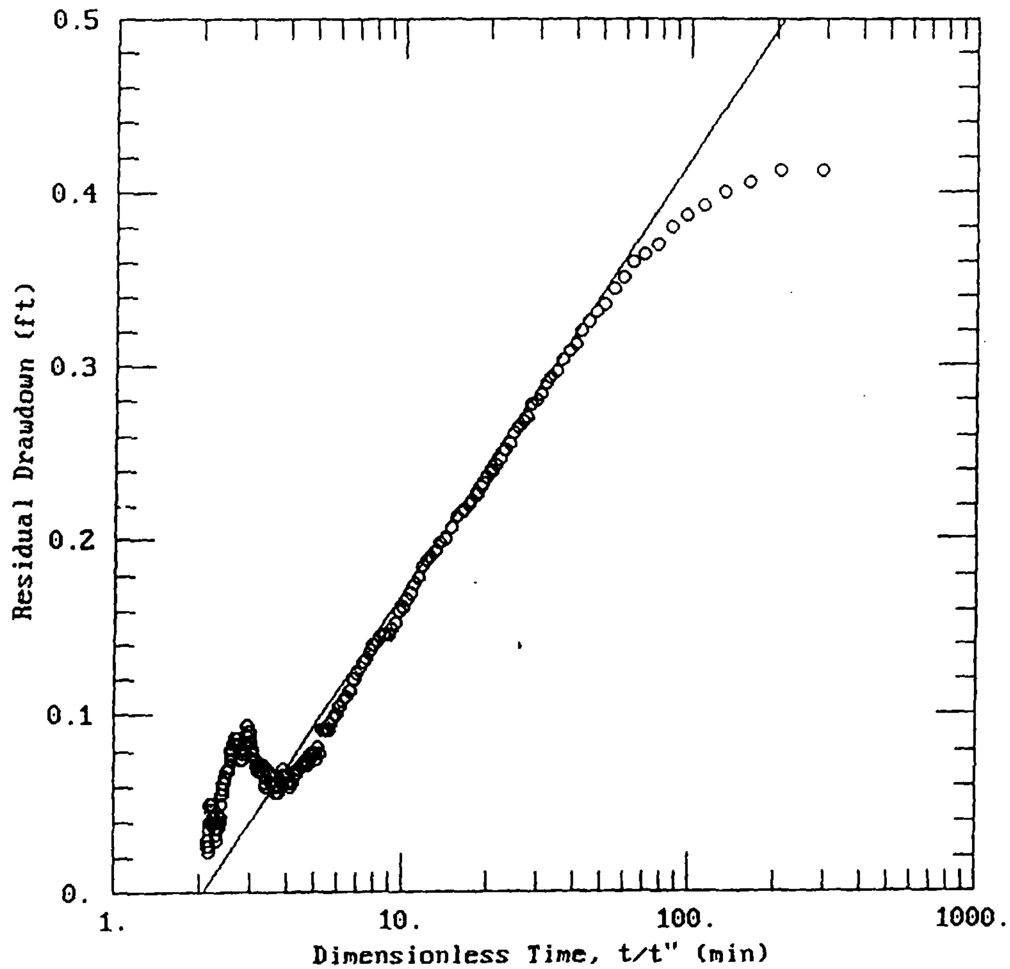
CLIENT: ACS PRP GROUP

COMPANY: MON[illegible]RY WATSON

LOCATION: GRIFFITH, IN

PROJECT: 4077.0040

RECOVERY ANALYSIS P51



DATA SET:
P51ALL.DAT
09/18/95

AQUIFER MODEL:
Confined

SOLUTION METHOD:
Theis Recovery

PROJECT DATA:
test date: MARCH '95
test well: EW1
obs. well: P51

TEST DATA:
Q = 1. gal/min
r = 10. ft
r_c = 0.25 ft
r_w = 0.6 ft
b = 12.8 ft

PARAMETER ESTIMATES:
T = 0.09868 ft^2/min
S' = 2.083

AQTESOLV

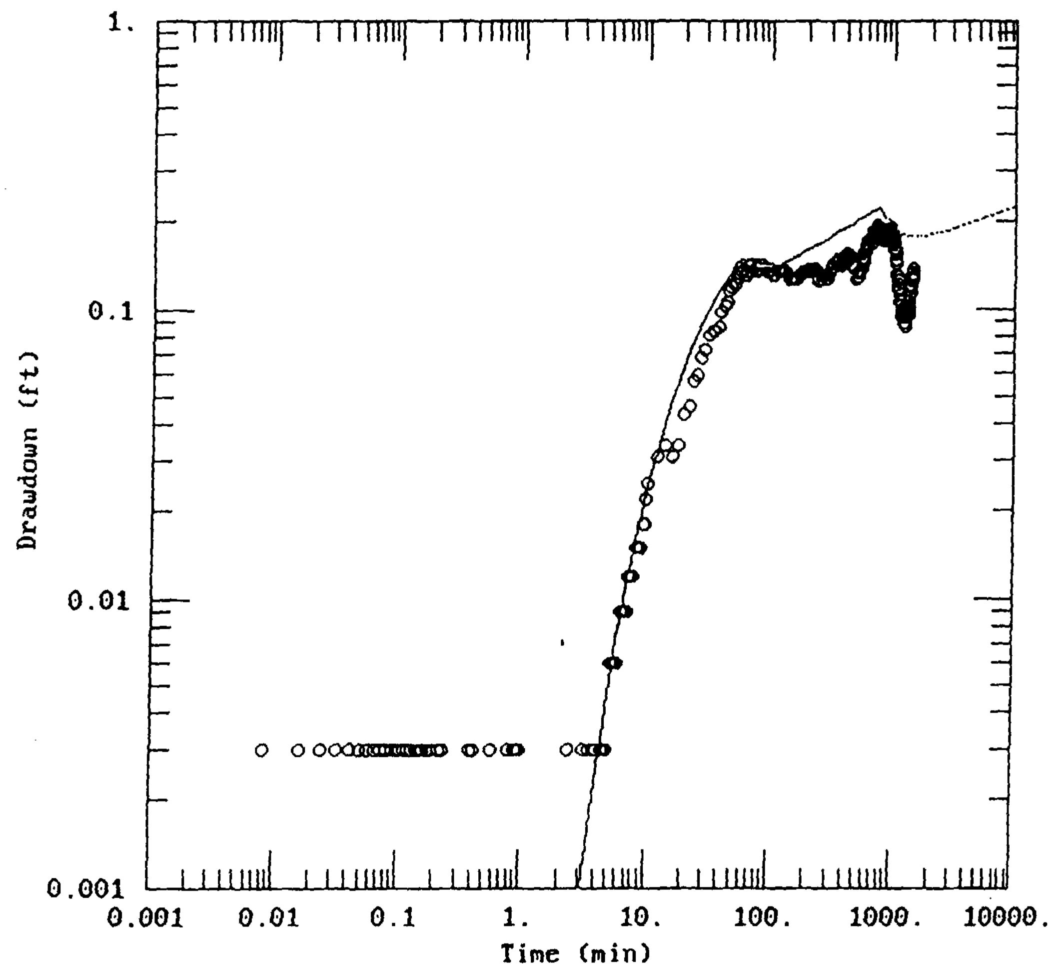
CLIENT: ACS PRP GROUP

COMPANY: MON[illegible] RY WATSON

LOCATION: GRIFFITH, INDIANA

PROJECT: 4077.0040

WELL P50 @ VARIABLE PUMPING RATE



DATA SET:
P50CORR.DAT
09/25/95

AQUIFER MODEL:
Confined

SOLUTION METHOD:
Theis

PROJECT DATA:
test date: MARCH 20-21, 1995
test well: EW1
obs. well: P50

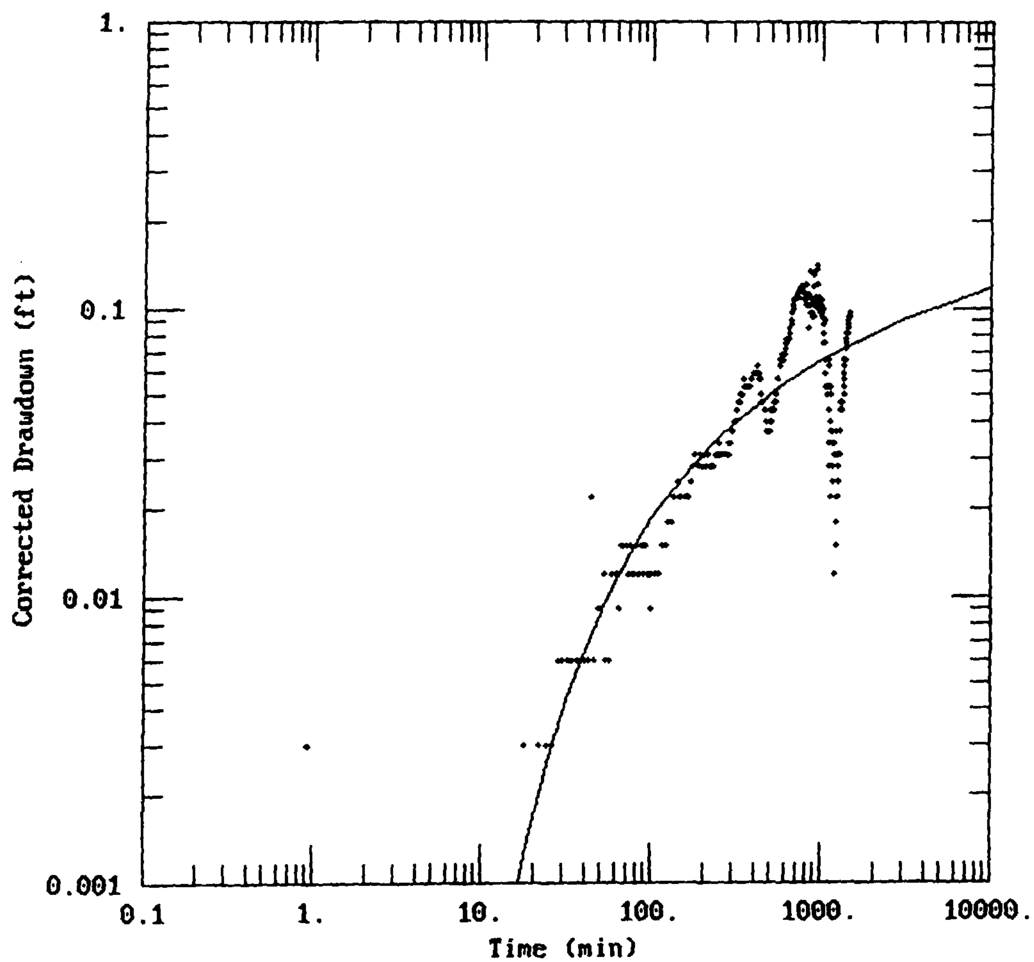
TEST DATA:
Q = 2. gal/min
r = 25. ft
b = 12.8 ft

PARAMETER ESTIMATES:
T = 0.1784 ft^2/min
S = 0.01208

AQTESOLV

CLIENT: ACS PRP GROUP	COMPANY: MONTGOMERY WATSON
LOCATION: GRIFFITH, INDIANA	PROJECT: 4077.0040

WELL P38 DRAWDOWN DATA



DATA SET:
P38DMOD.DAT
10/20/95

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Theis

PROJECT DATA:
test date: MARCH 20-21, 1995
test well: EW1
obs. well: P38

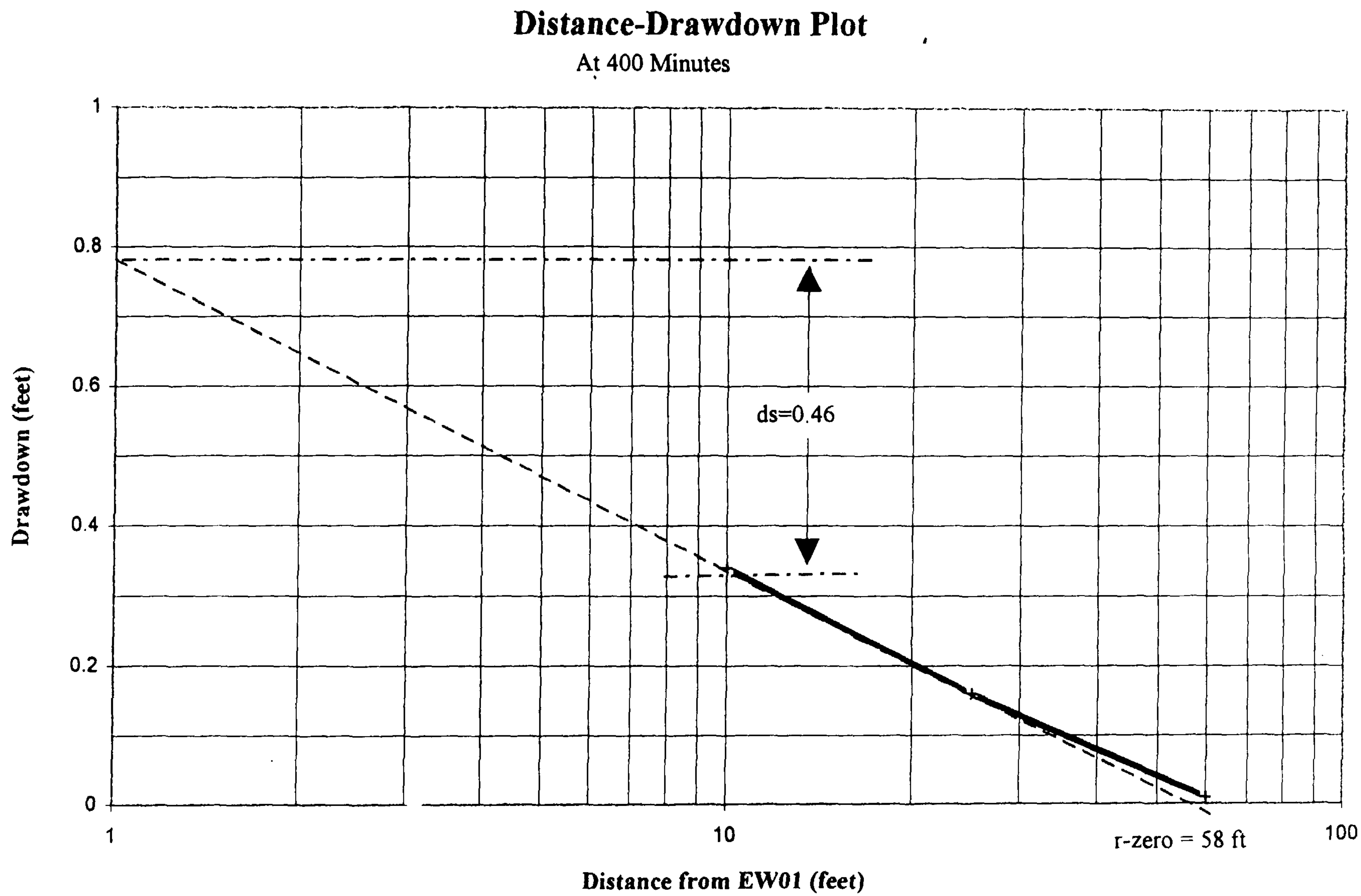
TEST DATA:
Q = 1. gal/min
r = 60. ft
r_c = 0.25 ft
r_w = 0.6 ft
b = 12.8 ft

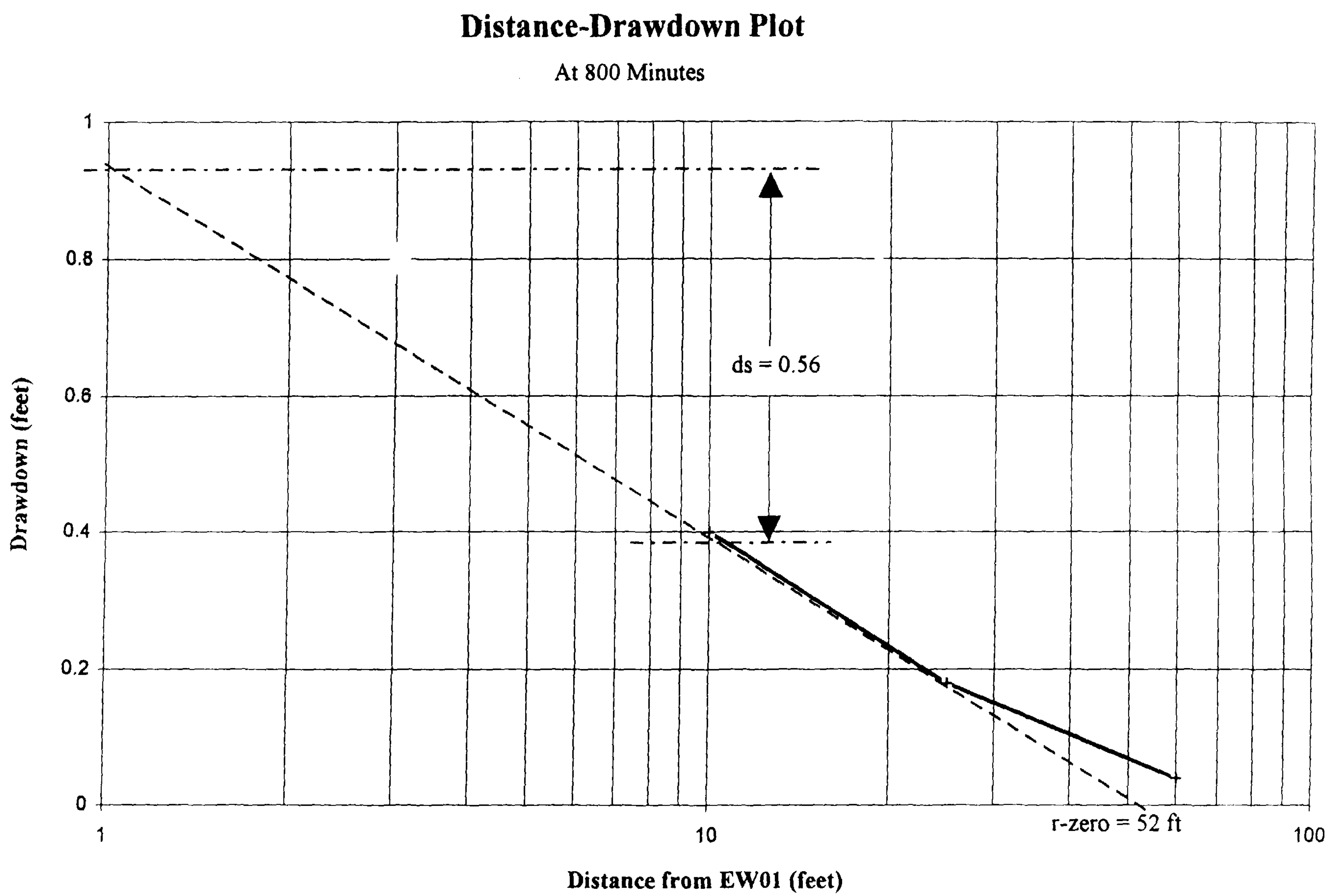
PARAMETER ESTIMATES:
T = 0.4608 ft^2/min
S = 0.01768

AQTESOLV

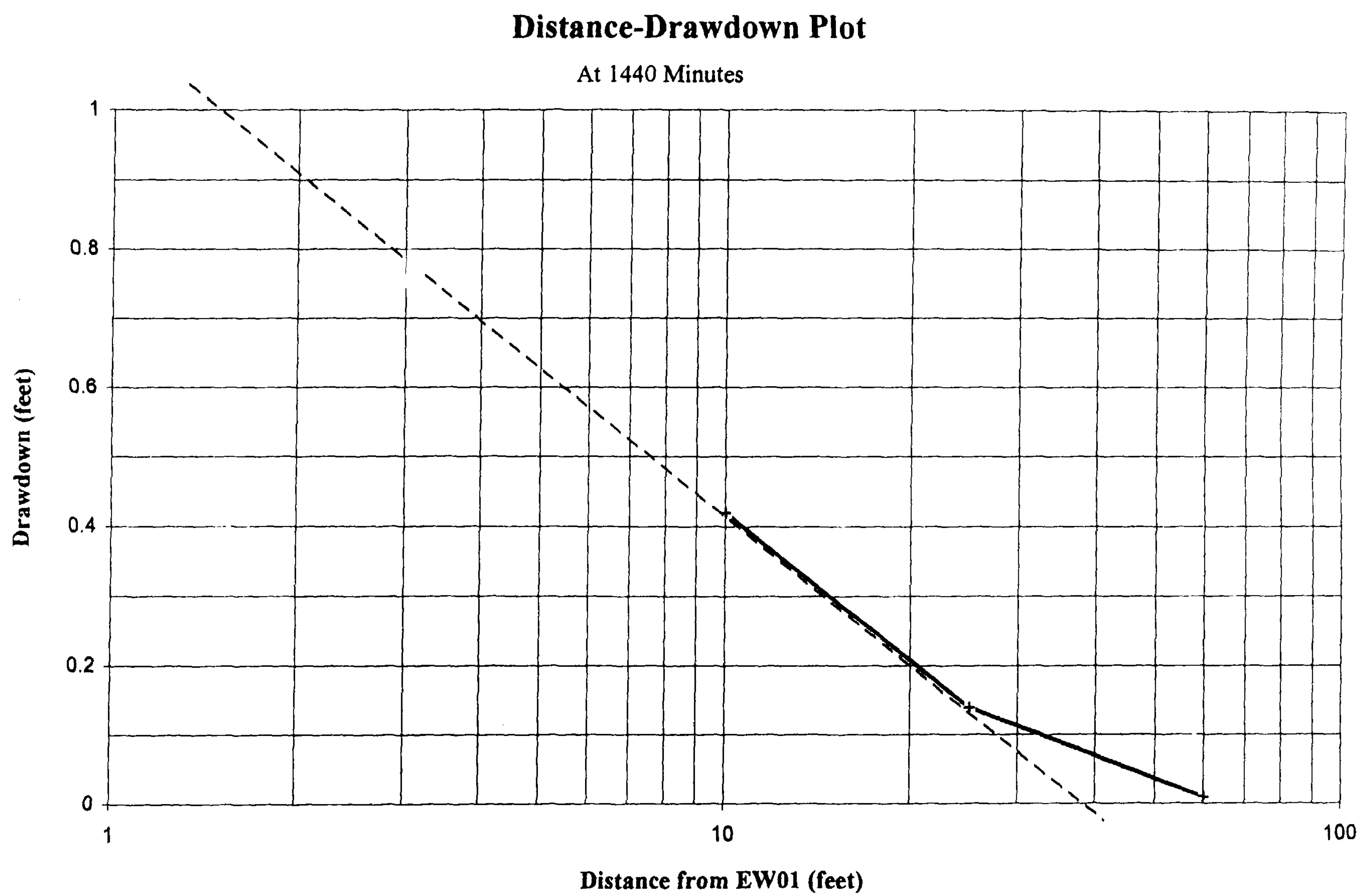
Table 2. Calculation by Jacob Recovery Method

Well	Distance	Drawdown 400 Min	800 Min	1440 Min
P51	10	0.34	0.4	0.42
P50	25	0.16	0.18	0.14
P38	60	0.01	0.04	0.04
Q	gpm	1	1	1
Q	cu.ft/min	0.13	0.13	0.13
D	ft	12.8	12.8	12.8
del-s	ft	0.46	0.56	0.7
r-zero	ft	58	52	40
kD	ft*ft	0.1064	0.0874	0.0699
S	unitless	0.3645	0.7449	1.8128
K	ft/min	8.3E-3	6.8E-3	5.5E-3
K	cm/sec	4.2E-3	3.5E-3	2.8E-3


Distance-Drawdown Plot
At 400 Minutes
Drawdown (feet)
1
0.8
0.6
0.4
0.2
0
ds=0.46
1
10
100
r-zero = 58 ft
Distance from EW01 (feet)



Distance-Drawdown Plot
At 800 Minutes
Drawdown (feet)
1
0.8
0.6
0.4
0.2
0
ds = 0.56
1
10
r-zero = 52 ft
100
Distance from EW01 (feet)



Distance-Drawdown Plot
At 1440 Minutes
Drawdown (feet)
1
0.8
0.6
0.4
0.2
0
1
10
100
Distance from EW01 (feet)

EW1 Corrected Drawdown

Time	Drawdown
0	0.022
0.0083	0.022
0.0166	0.018
0.025	0.018
0.0333	-0.009
0.0416	-0.006
0.05	0.009
0.0583	0.022
0.0666	0.028
0.075	0.025
0.0833	0.025
0.0916	0.022
0.1	0.022
0.1083	0.018
0.1166	0.022
0.125	0.025
0.1333	0.025
0.1416	0.161
0.15	0.126
0.1583	0.025
0.1666	0.072
0.175	0.107
0.1833	0.101
0.1916	0.078
0.2	0.085
0.2083	0.094
0.2166	0.123
0.225	0.142
0.2333	0.142
0.2416	0.142
0.25	0.135
0.2583	0.145
0.2666	0.161
0.275	0.161
0.2833	0.173
0.2916	0.173
0.3	0.173
0.3083	0.176
0.3166	0.176
0.325	0.192
0.3333	0.192
0.35	0.198
0.3666	0.198
0.3833	0.221
0.4	0.236
0.4166	0.233
0.4333	0.236
0.45	0.258
0.4666	0.274

0.4833	0.274
0.5	0.277
0.5166	0.287
0.5333	0.296
0.55	0.312
0.5666	0.331
0.5833	0.331
0.6	0.337
0.6166	0.353
0.6333	0.36
0.65	0.369
0.6666	0.375
0.6833	0.378
0.7	0.388
0.7166	0.388
0.7333	0.394
0.75	0.397
0.7666	0.407
0.7833	0.42
0.8	0.426
0.8166	0.429
0.8333	0.442
0.85	0.438
0.8666	0.448
0.8833	0.445
0.9	0.464
0.9166	0.467
0.9333	0.476
0.95	0.47
0.9666	0.489
0.9833	0.48
1	0.492
1.2	0.555
1.4	0.618
1.6	0.682
1.8	0.732
2	0.789
2.2	0.849
2.4	0.906
2.6	0.95
2.8	1.01
3	1.064
3.2	1.133
3.4	1.19
3.6	1.24
3.8	1.291
4	1.345
4.2	1.395
4.4	1.455
4.6	1.506
4.8	1.562

5	1.6
5.2	1.657
5.4	1.701
5.6	1.746
5.8	1.79
6	1.85
6.2	1.884
6.4	1.919
6.6	1.973
6.8	2.011
7	2.055
7.2	2.099
7.4	2.143
7.6	2.184
7.8	2.235
8	2.288
8.2	2.326
8.4	2.37
8.6	2.411
8.8	2.462
9	2.503
9.2	2.566
9.4	2.626
9.6	2.661
9.8	2.717
10	2.765
12	3.194
14	3.503
16	3.733
18	3.931
20	4.133
22	4.379
24	4.543
26	4.647
28	4.742
30	4.814
32	4.893
34	4.984
36	5.117
38	5.52
40	5.747
42	5.927
44	6.027
46	6.09
48	6.094
50	5.892
52	5.908
54	5.838
56	5.747
58	5.656
60	5.554

62	5.46
64	5.368
66	5.271
68	5.148
70	5.025
72	4.911
74	4.832
76	4.776
78	4.716
80	4.659
82	4.596
84	4.53
86	4.442
88	4.334
90	4.227
92	4.126
94	4.038
96	3.969
98	3.921
100	3.877
105	3.789
110	3.719
115	3.644
120	3.571
125	3.521
130	3.489
135	3.448
140	3.419
145	3.391
150	3.366
155	3.334
160	3.306
165	3.287
170	3.271
175	3.258
180	3.243
185	3.233
190	3.233
195	3.227
200	3.227
205	3.221
210	3.224
215	3.227
220	3.23
225	3.227
230	3.227
235	3.239
240	3.229
245	3.229
250	3.233
255	3.236

260	3.233
265	3.242
270	3.242
275	3.242
280	3.245
285	3.261
290	3.255
295	3.258
300	3.261
305	3.261
310	3.27
315	3.274
320	3.274
325	3.267
330	3.286
335	3.289
340	3.283
345	3.279
350	3.276
355	3.286
360	3.286
365	3.279
370	3.283
375	3.286
380	3.289
385	3.289
390	3.289
395	3.292
400	3.292
405	3.283
410	3.276
415	3.279
420	3.273
425	3.276
430	3.264
435	3.257
440	3.27
445	3.283
450	3.295
455	3.295
460	3.301
465	3.301
470	3.308
475	3.311
480	3.301
485	3.304
490	3.307
495	3.31
500	3.314
505	3.317
510	3.31

515	3.323
520	3.323
525	3.329
530	3.323
535	3.332
540	3.336
545	3.339
550	3.348
555	3.355
560	3.361
565	3.367
570	3.361
575	3.374
580	3.38
585	3.389
590	3.389
595	3.386
600	3.392
605	3.392
610	3.405
615	3.408
620	3.415
625	3.411
630	3.411
635	3.408
640	3.414
645	3.411
650	3.42
655	3.423
660	3.427
665	3.433
670	3.436
675	3.436
680	3.442
685	3.446
690	3.442
695	3.436
700	3.446
705	3.446
710	3.446
715	3.446
720	3.442
725	3.436
730	3.449
735	3.439
740	3.445
745	3.445
750	3.448
755	3.477
760	3.47
765	3.47

770	3.467
775	3.464
780	3.464
785	3.464
790	3.461
795	3.461
800	3.461
805	3.458
810	3.454
815	3.448
820	3.445
825	3.448
830	3.451
835	3.448
840	3.454
845	3.464
850	3.461
855	3.461
860	3.454
865	3.464
870	3.467
875	3.461
880	3.464
885	3.464
890	3.467
895	3.473
900	3.458
905	3.467
910	3.461
915	3.461
920	3.47
925	3.464
930	3.47
935	3.461
940	3.461
945	3.467
950	3.461
955	3.451
960	3.458
965	3.458
970	3.454
975	3.454
980	3.461
985	3.458
990	3.48
995	3.473
1000	3.464
1005	3.458
1010	3.448
1015	3.445
1020	3.442

1025	3.445
1030	3.439
1035	3.426
1040	3.426
1045	3.42
1050	3.407
1055	3.41
1060	3.407
1065	3.407
1070	3.404
1075	3.401
1080	3.398
1085	3.398
1090	3.395
1095	3.398
1100	3.388
1105	3.395
1110	3.395
1115	3.388
1120	3.404
1125	3.391
1130	3.382
1135	3.372
1140	3.366
1145	3.357
1150	3.36
1155	3.366
1160	3.347
1165	3.35
1170	3.347
1175	3.347
1180	3.35
1185	3.354
1190	3.347
1195	3.347
1200	3.344
1205	3.34
1210	3.34
1215	3.34
1220	3.347
1225	3.344
1230	3.35
1235	3.356
1240	3.356
1245	3.359
1250	3.356
1255	3.35
1260	3.34
1265	3.337
1270	3.337
1275	3.337

1280	3.327
1285	3.327
1290	3.33
1295	3.327
1300	3.33
1305	3.33
1310	3.34
1315	3.334
1320	3.334
1325	3.334
1330	3.334
1335	3.334
1340	3.34
1345	3.346
1350	3.362
1355	3.384
1360	3.375
1365	3.375
1370	3.381
1375	3.378
1380	3.381
1385	3.387
1390	3.39
1395	3.393
1400	3.4
1405	3.403
1410	3.403
1415	3.39
1420	3.39
1425	3.393
1430	3.399
1435	3.402
1440	3.421
1445	3.428

P51 Corrected Drawdown for Pumping and
Recovery Portions of Test

Time	Drawdown
0	-0.006
0.0083	-0.006
0.0166	-0.006
0.025	-0.006
0.0333	-0.003
0.0416	-0.006
0.05	-0.006
0.0583	-0.003
0.0666	-0.006
0.075	-0.003
0.0833	-0.006
0.0916	-0.006
0.1	-0.006
0.1083	-0.006
0.1166	-0.006
0.125	-0.006
0.1333	-0.006
0.1416	-0.006
0.15	-0.006
0.1583	-0.006
0.1666	-0.006
0.175	-0.006
0.1833	-0.006
0.1916	-0.006
0.2	-0.006
0.2083	-0.006
0.2166	-0.006
0.225	-0.006
0.2333	-0.006
0.2416	-0.006
0.25	-0.006
0.2583	-0.006
0.2666	-0.006
0.275	-0.006
0.2833	-0.006
0.2916	-0.006
0.3	-0.006
0.3083	-0.006
0.3166	-0.006
0.325	-0.006
0.3333	-0.006
0.35	-0.003
0.3666	-0.006
0.3833	-0.006
0.4	-0.006
0.4166	-0.006
0.4333	-0.006
0.45	-0.006
0.4666	-0.006
0.4833	-0.006
0.5	-0.006
0.5166	-0.006
0.5333	-0.006
0.55	-0.006
0.5666	-0.006
0.5833	-0.006
0.6	-0.006

0.6166	-0.006
0.6333	-0.006
0.65	-0.009
0.6666	-0.006
0.6833	-0.006
0.7	-0.006
0.7166	-0.006
0.7333	-0.006
0.75	-0.003
0.7666	-0.006
0.7833	-0.006
0.8	-0.006
0.8166	-0.006
0.8333	-0.006
0.85	-0.006
0.8666	-0.006
0.8833	-0.006
0.9	-0.006
0.9166	-0.006
0.9333	-0.006
0.95	-0.006
0.9666	-0.003
0.9833	-0.006
1	-0.006
1.2	-0.009
1.4	-0.009
1.6	-0.009
1.8	-0.006
2	-0.006
2.2	-0.009
2.4	-0.003
2.6	-0.006
2.8	-0.006
3	-0.006
3.2	-0.006
3.4	-0.006
3.6	-0.006
3.8	-0.003
4	-0.006
4.2	-0.006
4.4	-0.006
4.6	-0.006
4.8	-0.006
5	-0.006
5.2	-0.003
5.4	-0.003
5.6	-0.003
5.8	-0.003
6	-0.003
6.2	-0.003
6.4	0
6.6	0
6.8	0
7	0.003
7.2	0
7.4	0
7.6	0.003
7.8	0.003
8	0.003
8.2	0.006
8.4	0.006

8.6	0.003
8.8	0.006
9	0.006
9.2	0.006
9.4	0.009
9.6	0.012
9.8	0.009
10	0.009
12	0.022
14	0.035
16	0.034
18	0.054
20	0.067
22	0.079
24	0.089
26	0.099
28	0.108
30	0.115
32	0.124
34	0.134
36	0.144
38	0.15
40	0.16
42	0.163
44	0.169
46	0.166
48	0.169
50	0.172
52	0.182
54	0.182
56	0.182
58	0.191
60	0.198
62	0.198
64	0.201
66	0.211
68	0.214
70	0.214
72	0.217
74	0.22
76	0.22
78	0.223
80	0.227
82	0.23
84	0.23
86	0.233
88	0.236
90	0.236
92	0.239
94	0.243
96	0.243
98	0.243
100	0.243
105	0.249
110	0.252
115	0.259
120	0.265
125	0.258
130	0.262
135	0.268
140	0.271

145	0.274
150	0.278
155	0.278
160	0.278
165	0.281
170	0.284
175	0.29
180	0.294
185	0.294
190	0.297
195	0.297
200	0.3
205	0.3
210	0.3
215	0.3
220	0.303
225	0.303
230	0.293
235	0.3
240	0.3
245	0.303
250	0.3
255	0.303
260	0.303
265	0.306
270	0.306
275	0.306
280	0.309
285	0.309
290	0.313
295	0.316
300	0.316
305	0.319
310	0.322
315	0.325
320	0.329
325	0.332
330	0.332
335	0.325
340	0.325
345	0.328
350	0.331
355	0.331
360	0.331
365	0.331
370	0.331
375	0.335
380	0.338
385	0.338
390	0.341
395	0.344
400	0.344
405	0.344
410	0.344
415	0.347
420	0.344
425	0.344
430	0.344
435	0.341
440	0.338
445	0.338

450	0.338
455	0.338
460	0.338
465	0.341
470	0.331
475	0.328
480	0.331
485	0.331
490	0.331
495	0.334
500	0.337
505	0.337
510	0.341
515	0.344
520	0.344
525	0.344
530	0.347
535	0.347
540	0.35
545	0.354
550	0.357
555	0.36
560	0.363
565	0.366
570	0.37
575	0.37
580	0.37
585	0.373
590	0.373
595	0.376
600	0.376
605	0.379
610	0.382
615	0.386
620	0.376
625	0.376
630	0.379
635	0.379
640	0.382
645	0.382
650	0.385
655	0.388
660	0.392
665	0.392
670	0.395
675	0.395
680	0.398
685	0.398
690	0.398
695	0.401
700	0.401
705	0.401
710	0.401
715	0.401
720	0.401
725	0.395
730	0.398
735	0.395
740	0.401
745	0.398
750	0.401

755	0.398
760	0.398
765	0.401
770	0.404
775	0.398
780	0.401
785	0.401
790	0.401
795	0.398
800	0.401
805	0.398
810	0.401
815	0.395
820	0.395
825	0.395
830	0.398
835	0.401
840	0.401
845	0.411
850	0.404
855	0.404
860	0.404
865	0.401
870	0.417
875	0.401
880	0.404
885	0.404
890	0.407
895	0.411
900	0.411
905	0.411
910	0.407
915	0.401
920	0.417
925	0.414
930	0.42
935	0.414
940	0.414
945	0.414
950	0.414
955	0.407
960	0.414
965	0.411
970	0.411
975	0.421
980	0.411
985	0.404
990	0.404
995	0.404
1000	0.404
1005	0.394
1010	0.391
1015	0.391
1020	0.391
1025	0.394
1030	0.381
1035	0.405
1040	0.378
1045	0.372
1050	0.372
1055	0.372

1060	0.372
1065	0.382
1070	0.368
1075	0.372
1080	0.372
1085	0.368
1090	0.378
1095	0.378
1100	0.372
1105	0.378
1110	0.378
1115	0.378
1120	0.375
1125	0.372
1130	0.362
1135	0.362
1140	0.359
1145	0.362
1150	0.359
1155	0.372
1160	0.372
1165	0.375
1170	0.365
1175	0.368
1180	0.368
1185	0.368
1190	0.368
1195	0.375
1200	0.375
1205	0.378
1210	0.375
1215	0.381
1220	0.375
1225	0.372
1230	0.378
1235	0.375
1240	0.381
1245	0.381
1250	0.381
1255	0.381
1260	0.388
1265	0.381
1270	0.381
1275	0.384
1280	0.387
1285	0.384
1290	0.387
1295	0.391
1300	0.387
1305	0.387
1310	0.387
1315	0.384
1320	0.387
1325	0.391
1330	0.394
1335	0.394
1340	0.397
1345	0.4
1350	0.403
1355	0.407
1360	0.407

1365	0.407
1370	0.41
1375	0.413
1380	0.416
1385	0.416
1390	0.419
1395	0.416
1400	0.423
1405	0.426
1410	0.416
1415	0.409
1420	0.413
1425	0.413
1430	0.416
1435	0.416
1440	0.422

Start of Recovery Test (piezometer P51)

Time	Drawdown
1445	0.419
1450	0.413
1452	0.413
1454	0.406
1456	0.4
1458	0.393
1460	0.387
1462	0.381
1464	0.371
1466	0.365
1468	0.361
1470	0.352
1472	0.345
1474	0.336
1476	0.332
1478	0.326
1480	0.32
1482	0.313
1484	0.31
1486	0.304
1488	0.297
1490	0.294
1492	0.291
1494	0.284
1496	0.281
1498	0.278
1500	0.271
1502	0.268
1504	0.265
1506	0.262
1508	0.255
1510	0.252
1512	0.252
1514	0.246
1516	0.243
1518	0.239
1520	0.239
1522	0.236
1524	0.233
1526	0.23
1528	0.226
1530	0.226

1532	0.223
1534	0.22
1536	0.22
1538	0.217
1540	0.217
1545	0.214
1550	0.207
1555	0.201
1560	0.198
1565	0.194
1570	0.191
1575	0.188
1580	0.185
1585	0.178
1590	0.175
1595	0.169
1600	0.166
1605	0.162
1610	0.159
1615	0.153
1620	0.149
1625	0.146
1630	0.146
1635	0.146
1640	0.146
1645	0.143
1650	0.14
1655	0.14
1660	0.137
1665	0.133
1670	0.13
1675	0.13
1680	0.127
1685	0.124
1690	0.121
1695	0.121
1700	0.114
1705	0.114
1710	0.111
1715	0.111
1720	0.108
1725	0.105
1730	0.105
1735	0.101
1740	0.101
1745	0.098
1750	0.095
1755	0.095
1760	0.092
1765	0.092
1770	0.092
1775	0.092
1780	0.092
1785	0.092
1790	0.078
1795	0.082
1800	0.078
1805	0.075
1810	0.078
1815	0.078
1820	0.078

1825	0.075
1830	0.072
1835	0.072
1840	0.075
1845	0.072
1850	0.072
1855	0.072
1860	0.072
1865	0.069
1870	0.069
1875	0.069
1880	0.066
1885	0.066
1890	0.066
1895	0.062
1900	0.062
1905	0.062
1910	0.059
1915	0.062
1920	0.066
1925	0.062
1930	0.066
1935	0.066
1940	0.069
1945	0.066
1950	0.062
1955	0.059
1960	0.059
1965	0.059
1970	0.056
1975	0.056
1980	0.056
1985	0.059
1990	0.056
1995	0.059
2000	0.059
2005	0.062
2010	0.062
2015	0.066
2020	0.066
2025	0.066
2030	0.066
2035	0.069
2040	0.069
2045	0.059
2050	0.062
2055	0.065
2060	0.068
2065	0.068
2070	0.072
2075	0.072
2080	0.072
2085	0.068
2090	0.068
2095	0.072
2100	0.068
2105	0.068
2110	0.072
2115	0.072
2120	0.072
2125	0.075

2130	0.075
2135	0.075
2140	0.075
2145	0.078
2150	0.081
2155	0.081
2160	0.081
2165	0.085
2170	0.088
2175	0.091
2180	0.091
2185	0.094
2190	0.094
2195	0.094
2200	0.088
2205	0.088
2210	0.078
2215	0.081
2220	0.084
2225	0.084
2230	0.081
2235	0.078
2240	0.078
2245	0.075
2250	0.075
2255	0.075
2260	0.081
2265	0.081
2270	0.084
2275	0.087
2280	0.084
2285	0.087
2290	0.084
2295	0.084
2300	0.087
2305	0.087
2310	0.084
2315	0.084
2320	0.087
2325	0.084
2330	0.084
2335	0.084
2340	0.084
2345	0.081
2350	0.081
2355	0.081
2360	0.078
2365	0.075
2370	0.075
2375	0.075
2380	0.068
2385	0.071
2390	0.068
2395	0.071
2400	0.068
2405	0.068
2410	0.068
2415	0.068
2420	0.068
2425	0.068
2430	0.065

2435	0.065
2440	0.065
2445	0.062
2450	0.062
2455	0.062
2460	0.058
2465	0.058
2470	0.055
2475	0.058
2480	0.055
2485	0.055
2490	0.049
2495	0.042
2500	0.042
2505	0.039
2510	0.036
2515	0.036
2520	0.036
2525	0.039
2530	0.039
2535	0.039
2540	0.036
2545	0.03
2550	0.033
2555	0.033
2560	0.036
2565	0.039
2570	0.042
2575	0.039
2580	0.039
2585	0.036
2590	0.039
2595	0.046
2600	0.049
2605	0.042
2610	0.042
2615	0.042
2620	0.042
2625	0.039
2630	0.039
2635	0.046
2640	0.046
2645	0.046
2650	0.049
2655	0.049
2660	0.046
2665	0.049
2670	0.039
2675	0.036
2680	0.029
2685	0.029
2690	0.026
2695	0.023
2700	0.026
2705	0.029
2710	0.029
2715	0.029
2720	0.029

P50 Corrected Drawdown

Time	Drawdown
0	0.003
0.0083	0.003
0.0166	0.003
0.025	0.003
0.0333	0.003
0.0416	0.003
0.05	0.003
0.0583	0.003
0.0666	0.003
0.075	0.003
0.0833	0.003
0.0916	0.003
0.1	0.003
0.1083	0.003
0.1166	0.003
0.125	0.003
0.1333	0.003
0.1416	0.003
0.15	0.003
0.1583	0.003
0.1666	0.003
0.175	0.003
0.1833	0
0.1916	0.003
0.2	0
0.2083	0
0.2166	0.003
0.225	0
0.2333	0.003
0.2416	0
0.25	0
0.2583	0
0.2666	0
0.275	0
0.2833	0
0.2916	0
0.3	0
0.3083	0
0.3166	0
0.325	0
0.3333	0
0.35	0
0.3666	0
0.3833	0.003
0.4	0
0.4166	0.003
0.4333	0
0.45	0
0.4666	0
0.4833	0
0.5	0
0.5166	0
0.5333	0
0.55	0
0.5666	0
0.5833	0.003
0.6	0
0.6166	0

0.6333	0
0.65	0
0.6666	0
0.6833	0
0.7	0
0.7166	0
0.7333	0
0.75	0
0.7666	0
0.7833	0
0.8	0.003
0.8166	-0.003
0.8333	0
0.85	0
0.8666	0
0.8833	0
0.9	0.003
0.9166	0
0.9333	0.003
0.95	0.003
0.9666	0
0.9833	0.003
1	0.003
1.2	-0.003
1.4	-0.003
1.6	-0.003
1.8	-0.003
2	0
2.2	-0.003
2.4	0.003
2.6	0
2.8	0
3	0
3.2	0.003
3.4	0
3.6	0.003
3.8	0.003
4	0.003
4.2	0.003
4.4	0.003
4.6	0.003
4.8	0.003
5	0.003
5.2	0.006
5.4	0.006
5.6	0.006
5.8	0.006
6	0.006
6.2	0.009
6.4	0.009
6.6	0.009
6.8	0.009
7	0.012
7.2	0.009
7.4	0.012
7.6	0.012
7.8	0.012
8	0.012
8.2	0.015
8.4	0.015
8.6	0.015

8.8	0.015
9	0.015
9.2	0.015
9.4	0.018
9.6	0.018
9.8	0.022
10	0.025
12	0.031
14	0.034
16	0.031
18	0.034
20	0.043
22	0.046
24	0.056
26	0.059
28	0.068
30	0.072
32	0.081
34	0.084
36	0.084
38	0.087
40	0.097
42	0.103
44	0.106
46	0.116
48	0.119
50	0.122
52	0.128
54	0.132
56	0.135
58	0.138
60	0.131
62	0.131
64	0.134
66	0.141
68	0.134
70	0.137
72	0.141
74	0.137
76	0.134
78	0.137
80	0.141
82	0.137
84	0.141
86	0.137
88	0.137
90	0.134
92	0.137
94	0.134
96	0.137
98	0.134
100	0.131
105	0.131
110	0.134
115	0.134
120	0.137
125	0.134
130	0.134
135	0.131
140	0.127
145	0.127

150	0.127
155	0.127
160	0.127
165	0.131
170	0.131
175	0.134
180	0.134
185	0.134
190	0.134
195	0.134
200	0.137
205	0.137
210	0.134
215	0.134
220	0.134
225	0.134
230	0.137
235	0.127
240	0.124
245	0.13
250	0.13
255	0.127
260	0.13
265	0.13
270	0.127
275	0.13
280	0.127
285	0.13
290	0.133
295	0.133
300	0.136
305	0.139
310	0.139
315	0.143
320	0.143
325	0.146
330	0.146
335	0.146
340	0.149
345	0.142
350	0.145
355	0.142
360	0.142
365	0.142
370	0.142
375	0.145
380	0.148
385	0.148
390	0.148
395	0.152
400	0.155
405	0.152
410	0.152
415	0.152
420	0.148
425	0.152
430	0.152
435	0.142
440	0.142
445	0.142
450	0.142

455	0.139
460	0.139
465	0.139
470	0.139
475	0.139
480	0.126
485	0.126
490	0.126
495	0.132
500	0.129
505	0.132
510	0.135
515	0.135
520	0.135
525	0.135
530	0.135
535	0.138
540	0.142
545	0.145
550	0.145
555	0.148
560	0.151
565	0.157
570	0.157
575	0.157
580	0.161
585	0.164
590	0.164
595	0.164
600	0.164
605	0.167
610	0.173
615	0.173
620	0.173
625	0.173
630	0.176
635	0.176
640	0.166
645	0.173
650	0.176
655	0.176
660	0.179
665	0.182
670	0.179
675	0.179
680	0.185
685	0.185
690	0.188
695	0.188
700	0.188
705	0.185
710	0.188
715	0.188
720	0.192
725	0.192
730	0.195
735	0.182
740	0.185
745	0.185
750	0.185
755	0.182

760	0.182
765	0.185
770	0.188
775	0.185
780	0.185
785	0.185
790	0.182
795	0.178
800	0.178
805	0.175
810	0.172
815	0.172
820	0.172
825	0.175
830	0.178
835	0.178
840	0.182
845	0.188
850	0.182
855	0.182
860	0.178
865	0.178
870	0.182
875	0.175
880	0.182
885	0.178
890	0.178
895	0.182
900	0.172
905	0.182
910	0.182
915	0.182
920	0.188
925	0.185
930	0.191
935	0.182
940	0.182
945	0.178
950	0.182
955	0.175
960	0.178
965	0.175
970	0.175
975	0.175
980	0.172
985	0.169
990	0.163
995	0.169
1000	0.166
1005	0.163
1010	0.159
1015	0.159
1020	0.159
1025	0.156
1030	0.144
1035	0.147
1040	0.144
1045	0.131
1050	0.128
1055	0.128
1060	0.128

1065	0.128
1070	0.125
1075	0.125
1080	0.122
1085	0.118
1090	0.115
1095	0.118
1100	0.112
1105	0.115
1110	0.112
1115	0.112
1120	0.106
1125	0.103
1130	0.106
1135	0.103
1140	0.099
1145	0.099
1150	0.093
1155	0.096
1160	0.096
1165	0.096
1170	0.096
1175	0.096
1180	0.096
1185	0.099
1190	0.093
1195	0.089
1200	0.093
1205	0.093
1210	0.093
1215	0.096
1220	0.089
1225	0.086
1230	0.093
1235	0.089
1240	0.093
1245	0.096
1250	0.093
1255	0.099
1260	0.102
1265	0.102
1270	0.105
1275	0.095
1280	0.098
1285	0.098
1290	0.098
1295	0.102
1300	0.098
1305	0.098
1310	0.098
1315	0.095
1320	0.098
1325	0.098
1330	0.102
1335	0.105
1340	0.108
1345	0.111
1350	0.114
1355	0.117
1360	0.117
1365	0.117

1370	0.121
1375	0.127
1380	0.127
1385	0.13
1390	0.13
1395	0.136
1400	0.126
1405	0.129
1410	0.126
1415	0.129
1420	0.129
1425	0.129
1430	0.133
1435	0.136
1440	0.133
1445	0.136

P38 Corrected Drawdown

Time	Drawdown
0	-0.003
0.0083	-0.003
0.0166	-0.003
0.025	-0.003
0.0333	-0.003
0.0416	-0.003
0.05	-0.003
0.0583	-0.003
0.0666	-0.003
0.075	0
0.0833	-0.003
0.0916	-0.003
0.1	0
0.1083	-0.003
0.1166	-0.003
0.125	0
0.1333	0
0.1416	-0.003
0.15	0
0.1583	-0.003
0.1666	0
0.175	-0.003
0.1833	0
0.1916	-0.003
0.2	0
0.2083	-0.003
0.2166	0
0.225	-0.003
0.2333	0
0.2416	-0.003
0.25	-0.003
0.2583	-0.003
0.2666	0
0.275	0
0.2833	-0.003
0.2916	-0.003
0.3	-0.003
0.3083	0
0.3166	-0.003
0.325	0
0.3333	0
0.35	-0.003
0.3666	-0.003
0.3833	-0.003
0.4	0
0.4166	0
0.4333	-0.003
0.45	-0.003
0.4666	-0.003
0.4833	-0.003
0.5	-0.003
0.5166	-0.003
0.5333	-0.003
0.55	-0.003
0.5666	-0.003
0.5833	-0.003
0.6	-0.003
0.6166	-0.003
0.6333	-0.003

0.65	-0.003
0.6666	-0.003
0.6833	-0.003
0.7	-0.003
0.7166	-0.003
0.7333	-0.003
0.75	0
0.7666	-0.003
0.7833	-0.003
0.8	-0.003
0.8166	-0.003
0.8333	-0.006
0.85	-0.006
0.8666	-0.003
0.8833	-0.003
0.9	0
0.9166	0.003
0.9333	0.003
0.95	0.003
0.9666	0
0.9833	-0.003
1	0
1.2	-0.003
1.4	-0.003
1.6	-0.006
1.8	-0.003
2	0
2.2	-0.003
2.4	-0.003
2.6	-0.003
2.8	-0.003
3	-0.003
3.2	-0.003
3.4	-0.003
3.6	-0.003
3.8	-0.003
4	-0.003
4.2	0
4.4	-0.003
4.6	-0.003
4.8	-0.003
5	-0.006
5.2	-0.003
5.4	-0.003
5.6	-0.003
5.8	-0.003
6	-0.003
6.2	-0.003
6.4	-0.003
6.6	-0.003
6.8	0
7	0
7.2	0
7.4	-0.003
7.6	0
7.8	0
8	0
8.2	-0.003
8.4	0
8.6	-0.003
8.8	0

9	0
9.2	-0.003
9.4	0
9.6	0
9.8	0
10	0
12	0
14	0
16	0
18	0.003
20	0
22	0.003
24	0.003
26	0.003
28	0.006
30	0.006
32	0.006
34	0.006
36	0.006
38	0.006
40	0.006
42	0.006
44	0.022
46	0.006
48	0.009
50	0.009
52	0.012
54	0.006
56	0.006
58	0.012
60	0.012
62	0.012
64	0.009
66	0.015
68	0.015
70	0.015
72	0.012
74	0.015
76	0.012
78	0.012
80	0.015
82	0.012
84	0.012
86	0.015
88	0.015
90	0.012
92	0.015
94	0.012
96	0.012
98	0.012
100	0.009
105	0.012
110	0.012
115	0.015
120	0.015
125	0.018
130	0.018
135	0.022
140	0.025
145	0.022
150	0.022

155	0.022
160	0.022
165	0.022
170	0.025
175	0.028
180	0.031
185	0.028
190	0.031
195	0.028
200	0.031
205	0.028
210	0.028
215	0.031
220	0.028
225	0.028
230	0.028
235	0.031
240	0.031
245	0.034
250	0.031
255	0.031
260	0.031
265	0.031
270	0.031
275	0.031
280	0.031
285	0.034
290	0.034
295	0.037
300	0.037
305	0.04
310	0.04
315	0.044
320	0.047
325	0.047
330	0.05
335	0.05
340	0.05
345	0.053
350	0.056
355	0.053
360	0.053
365	0.053
370	0.053
375	0.053
380	0.056
385	0.056
390	0.059
395	0.059
400	0.059
405	0.059
410	0.063
415	0.059
420	0.059
425	0.056
430	0.056
435	0.05
440	0.047
445	0.047
450	0.047
455	0.044

460	0.044
465	0.04
470	0.04
475	0.037
480	0.037
485	0.037
490	0.037
495	0.044
500	0.04
505	0.04
510	0.044
515	0.047
520	0.047
525	0.044
530	0.047
535	0.047
540	0.05
545	0.056
550	0.056
555	0.056
560	0.063
565	0.066
570	0.066
575	0.066
580	0.069
585	0.066
590	0.069
595	0.069
600	0.069
605	0.072
610	0.075
615	0.078
620	0.075
625	0.075
630	0.078
635	0.078
640	0.081
645	0.085
650	0.088
655	0.091
660	0.097
665	0.1
670	0.103
675	0.103
680	0.107
685	0.107
690	0.11
695	0.11
700	0.11
705	0.11
710	0.113
715	0.113
720	0.11
725	0.11
730	0.116
735	0.11
740	0.119
745	0.116
750	0.119
755	0.116
760	0.116

765	0.119
770	0.119
775	0.119
780	0.113
785	0.107
790	0.107
795	0.103
800	0.122
805	0.11
810	0.103
815	0.103
820	0.103
825	0.113
830	0.113
835	0.085
840	0.103
845	0.135
850	0.097
855	0.11
860	0.107
865	0.094
870	0.107
875	0.097
880	0.119
885	0.103
890	0.119
895	0.132
900	0.094
905	0.11
910	0.107
915	0.107
920	0.135
925	0.11
930	0.141
935	0.1
940	0.103
945	0.138
950	0.122
955	0.097
960	0.11
965	0.1
970	0.103
975	0.097
980	0.103
985	0.094
990	0.094
995	0.107
1000	0.103
1005	0.1
1010	0.088
1015	0.075
1020	0.081
1025	0.1
1030	0.066
1035	0.091
1040	0.075
1045	0.053
1050	0.059
1055	0.05
1060	0.05
1065	0.05

1070	0.05
1075	0.053
1080	0.063
1085	0.034
1090	0.044
1095	0.066
1100	0.028
1105	0.053
1110	0.04
1115	0.053
1120	0.05
1125	0.04
1130	0.022
1135	0.037
1140	0.034
1145	0.037
1150	0.025
1155	0.037
1160	0.028
1165	0.028
1170	0.031
1175	0.031
1180	0.012
1185	0.012
1190	0.031
1195	0.034
1200	0.022
1205	0.018
1210	0.015
1215	0.031
1220	0.037
1225	0.022
1230	0.025
1235	0.022
1240	0.025
1245	0.031
1250	0.028
1255	0.031
1260	0.031
1265	0.037
1270	0.037
1275	0.044
1280	0.047
1285	0.044
1290	0.047
1295	0.047
1300	0.047
1305	0.044
1310	0.044
1315	0.044
1320	0.047
1325	0.047
1330	0.05
1335	0.053
1340	0.056
1345	0.059
1350	0.063
1355	0.066
1360	0.066
1365	0.072
1370	0.072

1375	0.075
1380	0.078
1385	0.078
1390	0.081
1395	0.081
1400	0.085
1405	0.088
1410	0.085
1415	0.088
1420	0.091
1425	0.091
1430	0.094
1435	0.094
1440	0.097
1445	0.097

APPENDIX A. AQUIFER PROPERTY ANALYSIS

Appendix A-2. Groundwater Model

The perimeter groundwater control system (PGCS) was developed as the system to collect and treat contaminated groundwater at the downgradient boundary of the ACS NPL Site. The system will consist of a trench cut across the water table, perpendicular to the flow direction downgradient of the site between the ACS facility and the wetlands area to the west. Groundwater flow modeling was used in conjunction with the existing hydraulic and hydrogeologic data that has been gathered at the site to establish the optimal location and orientation of the extraction trench, and to estimate the resulting extraction rates to be used in the design of the above-ground treatment system.

Visual Modflow was selected to model the groundwater extraction in the upper aquifer at the ACS site. Visual Modflow was developed by Nilson Guiguer and Thomas Franz at Waterloo Hydrogeologic Software for use on IBM compatible PC platform. Visual Modflow combines pre- and post-processors with the U.S. Geologic (USGS) Modflow Model and the USGS Modpath Model, to provide a "user-friendly" modeling interface. In the model, the USGS Modflow model represents the groundwater flow system, while Modpath represents the potential groundwater flow paths which result from the aquifer properties and gradients.

Modflow was implemented during the Remedial Investigation (RI) to evaluate the groundwater flow paths, and it was used in the Baseline Risk Assessment to estimate future plume behavior The RI Model was updated during the Feasibility Study (FS) phase to evaluate potential pump and treat scenarios, and to evaluate the probable effects of cut-off walls.

The scope of the groundwater modeling performed as part of the Remedial Design (RD) Phase includes:

- Evaluating the pumping test results and verifying that they were consistent with the aquifer properties that had been determined by bail down tests conducted at multiple upper aquifer points during the RI.

- Running the baseline model which was established and matched to field conditions during the RI and FS.

- Using the "drain" (DRN) module to represent segments of the groundwater extraction trench along the western and northern sides of the ACS facility to represent the Perimeter Groundwater Containment System (PGCS).

- Using the Modpath component of the USGS modeling system to evaluate the groundwater capture zones for the planned extraction trench.

- Iterating through the previous steps to estimate optimal location, length, and total drawdown for the groundwater extraction trench, which would result in capture of upper aquifer groundwater contamination between the ACS facility and the wetlands on the north and west.

MODEL SPECIFICATIONS

Modflow is a three-dimensional finite-difference groundwater flow model developed by the USGS. The model simulates groundwater flow within aquifers using a block-centered finite-difference approach. Multiple layers can be simulated as confined, unconfined, or a combination of both. The model can simulate external stresses including: flow to wells, areal recharge, evapotranspiration, flow to drains, flow through river beds, and general head-boundary conditions.

Modpath is a post-processing software package developed by the USGS for use with the Modflow model. Modpath uses a semi-analytical particle tracking scheme that computes three-dimensional path lines and represent potential groundwater flow paths.

Modeling in this implementation was limited to the upper aquifer, since the objective was to evaluate response of the upper aquifer to a perimeter groundwater extraction system and develop estimates of the likely volumes of groundwater to be extracted for above ground treatment.

MODEL PARAMETERS

The Modflow model for the ACS Site was developed to represent the hydraulic properties and aquifer geometries determined during the RI. The input parameters include: hydraulic conductivity values, the elevation of the base of the upper aquifer, the watertable elevation, and recharge/discharge. These input parameters provided the basis for the model input and history match. As part of this investigation, a pumping test was conducted in March of 1995 to further evaluate the hydraulic characteristics of the upper aquifer. The results of the pumping test were consistent with the aquifer properties that had been determined during the RI. Therefore, the model implemented and tested in the remedial investigation was used to evaluate the potential effects of groundwater extraction at the site.

The modeling was conducted with a single set of time and space units. "Feet" were used as the length unit and "days" were used as the time unit. Consequently, the parameters of grid spacing, aquifer thickness, and watertable elevation were reported in feet. Hydraulic conductivity units were in feet per day; transmissivity units were in feet-squared per day. Volumes of discharge and recharge were reported in cubic feet per day. The Strongly Implicit Procedure (SIP) was used to solve the model.

A one-layer, 30-column, 24-row finite difference grid, with 100-foot grid spacing was used for the simulation. The model was not implemented to include the lower aquifer. Input variables were used in the model to define the following: 1) aquifer geometry, 2) boundary conditions, 3) hydraulic characteristics of the aquifer, and 4) recharge/discharge interactions with the atmosphere and surface water bodies. The use of each of these groups of input parameters is discussed below. Figure 1 displays the orientation of rows and columns for the modeled area.

Aquifer Geometry
Aquifer thickness is variable across the site, because a watertable aquifer is being modeled and the saturated thickness varies with the watertable elevation. The base of the aquifer is assumed to be 620 feet MSL. The watertable elevation is variable across the site, at 630 to 634 feet MSL in the ACS facility, to less than 625 feet MSL in the vicinity of the municipal leachate collection system. The model was implemented to replicate these elevations, which are representative of the surface water and groundwater elevations established at monitoring wells, piezometers, and staff gauges during the RI.

Boundary Conditions
The General Head Boundary (GHB) module was used to simulate the boundary conditions surrounding the site. GHB entries were made for each of the exterior nodes of the model. The "head" specified for each was the average groundwater elevation observed along that boundary during the RI. The conductivity values for the aquifer were variable across the site, established by aquifer tests performed during the remedial investigation, and confirmed by the pumping test conducted in March of 1995.

Hydraulic Properties
Aquifer properties are required for each layer of the model (a single layer for this implementation). The properties required include specific yield, storativity, and hydraulic conductivity. The model internally calculates the transmissivity for each node by multiplying the hydraulic conductivity value by the saturated thickness, calculated as the difference between the watertable elevation and elevation of the bottom of the layer (620 feet MSL for this model).

Specific yield for the upper aquifer was assigned a value of 0.25. Since the aquifer being simulated is unconfined, it was not necessary to assign a storativity value. The hydraulic conductivity of the original model was based on the baildown tests conducted at the upper aquifer monitoring wells installed during the RI. The average value was confirmed by the pumping test conducted in March of 1995. The hydraulic conductivity values assigned in the model vary across the site, from 2.4 to 24 feet/day (8.5×10^{-4} to 8.5×10^{-3} cm/sec).

Surface Water Bodies
Surface water bodies at the site include the following: the ACS firepond, the Griffith Landfill dewatering pond, the drainage ditch in the wetland west of the ACS facility, and the drainage ditch between the Griffith Landfill and the Off-Site Containment Area. These surface water bodies were represented using the river module (RIV). The RIV module provides a method for the exchange between groundwater and surface water. River nodes are assigned surface water elevations and conductivities that represent a resistance to flow between the aquifer and the surface water body.

Recharge/Discharge
Recharge is both lateral and vertical at the ACS Site. Lateral recharge occurs to the upper aquifer from north and east of the site. For the simulation, lateral recharge is controlled by the General Head Boundary assignments in column 30 and row 24.

The general areal recharge (vertical recharge) was applied to represent an average of six inches per year of infiltrating precipitation (0.00137 feet/day) which was incorporated into the RCH module. The RCH module was used to provide locally variable recharge amounts across the site. The highest local recharge amounts were applied across the ACS facility, where there is little relief and no vegetation to promote runoff and evapotranspiration. Storm sewers drain much of the site directly to the fire pond. Based on a calculation of runoff area to fire pond area, recharge to the pond was set to about 50 times the average annual infiltration rate. Since the wetland areas are groundwater discharge areas, no recharge amounts were assigned in the wetland areas.

Primary discharge from the upper aquifer occurs toward the landfill dewatering area in the southwest, and toward the drainage ditch which runs to the northwest and west of the site. These were simulated by establishing "river nodes" with assigned head values in the RIV module.

MODEL IMPLEMENTATION
Existing Conditions Simulation
The model was implemented with the physical and hydraulic data from the RI, which was confirmed by the RD pumping test. The model was implemented to replicate the existing conditions at the site, with surface water discharge to the ACS firepond and groundwater discharge to the excavation area in the Griffith Municipal Landfill. Figure 2 is a plot of the watertable map developed from the October 30, 1995 water level measurements at approximately 75 monitoring wells, piezometers, and staff gauges.

Figure 3 represents the baseline modeling result. It is evident that the site watertable is well represented by the model in the zones of known groundwater contamination. The watertable match is less accurate across the Griffith Landfill Area where RI data was limited.

Future Conditions Simulation
The objective of the PGCS is to contain groundwater contamination, limiting the off-site migration of contaminants in the upper aquifer north and west of the ACS facility. It is not desirable to dewater the upper aquifer; in fact, it is important to avoid dewatering the upper aquifer as much as possible, because the wetlands to the west of the site are formed by groundwater discharging from the upper aquifer. The goal is to design the PGCS to establish hydraulic control along the alignment at which contaminants have the potential to migrate off-site, with the minimal rate of upper aquifer dewatering.

The RD modeling effort was conducted to develop a groundwater extraction approach consistent with these goals. Modeling was used to evaluate several potential locations for a groundwater extraction trench. It was also used to develop estimates of the groundwater extraction rates that would be necessary to establish the hydraulic control to minimize the potential for off-site contaminant migration, yet have minimal effect on the wetlands to the west.

Modflow provides several mechanisms to represent groundwater extraction during a simulation. The two primary mechanisms are "wells" and "drains." A drain node maintains a constant head, using a variable extraction rate. A well node maintains a constant extraction rate, and allows the groundwater elevation (head) to vary. For this simulation, it is of interest to establish the constant lowering of the head that is sufficient to establish hydraulic control. The pumping rate is one of the primary "unknowns" that needs to be determined. Therefore, it was appropriate to use the drain module (DRN) to represent the extraction trench. The other primary unknown is the length and orientation of the extraction trench which would result in the most efficient hydraulic control of the upper aquifer. Optimal trench orientation scenarios were determined from the modeling results.

The orientation of the extraction trench was selected to conform in general to the 634 foot contour line within the model, along the alignment north and west of the ACS Site. A trench depth of six feet was selected (the depth could have range from a few feet to total penetration of the upper aquifer, without significantly affecting the model outcome). The "conductivity" of each trench node was established by trial and error, to be 190 feet per day. Through trial and error, this value was found to lower the head in the trench area from the original 634 feet elevation to 630 feet elevation. Water levels measured in 1996 show that the actual water level at that location was approximately two feet lower in October 1996 than the 1990 when the model was developed. However, the model still provides a qualitative representation of the aquifer condition in 1996. The maximum error introduced by this difference would be a potential over-estimated of the pumping rate by 10 to 15 percent.

The Modpath component of the model was used to evaluate the capture efficiency of the modeled extraction trench. The Modpath module was used to place "particles" in the upper aquifer to represent areas of groundwater contamination. The groundwater flow velocity vectors calculated by the model then "move" the particles downgradient, and the resulting particle track lines show the ultimate disposition of each particle. Complete capture of contaminants is indicated by the termination of all particle track lines at the extraction trench.

Visual Modflow was used iteratively to select the optimal location of the dewatering trench alignment, and to establish the minimum necessary extraction rate to affect complete contaminant capture in the upper aquifer. The output file for the optimized model run is attached. It provides the numerical representation of input parameters and output water elevations in the upper aquifer. Figure 4 provides a graphic representation of the successful model run. It includes a contour map of the watertable configuration which would result from the simulated extraction trench, and also plots the particle tracks representing contaminant transport flow paths.

The steady state groundwater extraction rate to maintain a four-foot drawdown in the extraction trench is approximately 12 gallons per minute (2,382 cubic feet per day). Initial average extraction rates would probably be 200 to 300 percent higher. Extraction rates will vary throughout the year as precipitation and evapotranspiration change with the seasons. The simulation was based on an assumption that, on average, 15 percent of the annual precipitation infiltrates to become groundwater in the upper aquifer.

<u>Attachments</u>

Abstract: MODFLOW
Abstract: MODPATH
Figure 1. Finite Difference Grid Orientation
Figure 2. Watertable Contour Map from October 30, 1995 Water Elevations
Figure 3. Modeled Baseline Watertable Contour Map
Figure 4. Modeled Groundwater Capture, with Extraction Trench
Modflow Input/Output Listing for ACS Remedial Design

PJV/MSR
APNDX-A2.DOC
4077.0050

A MODULAR THREE-DIMENSIONAL FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

By Michael G. McDonald and Arlen W. Harbaugh

ABSTRACT

This report presents a finite-difference model and its associated modular computer program. The model simulates flow in three dimensions. The report includes detailed explanations of physical and mathematical concepts on which the model is based and an explanation of how those concepts are incorporated in the modular structure of the computer program. The modular structure consists of a Main Program and a series of highly independent subroutines called "modules." The modules are grouped into "packages." Each package deals with a specific feature of the hydrologic system which is to be simulated, such as flow from rivers or flow into drains, or with a specific method of solving linear equations which describe the flow system, such as the Strongly Implicit Procedure or Slice-Successive Overrelaxation.

The division of the program into modules permits the user to examine specific hydrologic features of the model independently. This also facilitates development of additional capabilities because new packages can be added to the program without modifying the existing packages. The input and output systems of the computer program are also designed to permit maximum flexibility.

Ground-water flow within the aquifer is simulated using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of confined and unconfined. Flow associated with external stresses, such as wells, areal recharge, evapotranspiration, drains, and streams, can also be simulated. The finite-difference equations can be solved using either the Strongly Implicit Procedure or Slice-Successive Overrelaxation.

The program is written in FORTRAN 77 and will run without modification on most computers that have a FORTRAN 77 compiler. For each program module, this report includes a narrative description, a flow chart, a list of variables, and a module listing.

ABSTRACT

A particle tracking post-processing package was developed to compute three-dimensional path lines based on output from steady-state simulations obtained with the U. S. Geological Survey modular three-dimensional finite-difference ground-water flow model. The package consists of two FORTRAN 77 computer programs: (1) MODPATH, which calculates pathlines, and (2) MODPATH-PLOT, which presents results graphically.

MODPATH uses a semi-analytical particle tracking scheme. The method is based on the assumption that each directional velocity component varies linearly within a grid cell in its own coordinate direction. This assumption allows an analytical expression to be obtained describing the flow path within a grid cell. Given the initial position of a particle anywhere in a cell, the coordinates of any other point along its path line within the cell, and the time of travel between them, can be computed directly.

Data is input to MODPATH and MODPATH-PLOT through a combination of files and interactive dialogue. Examples of how to use MODPATH and MODPATH-PLOT are provided for a sample problem. Listings of the computer codes and detailed descriptions of input data format and program options are also presented.

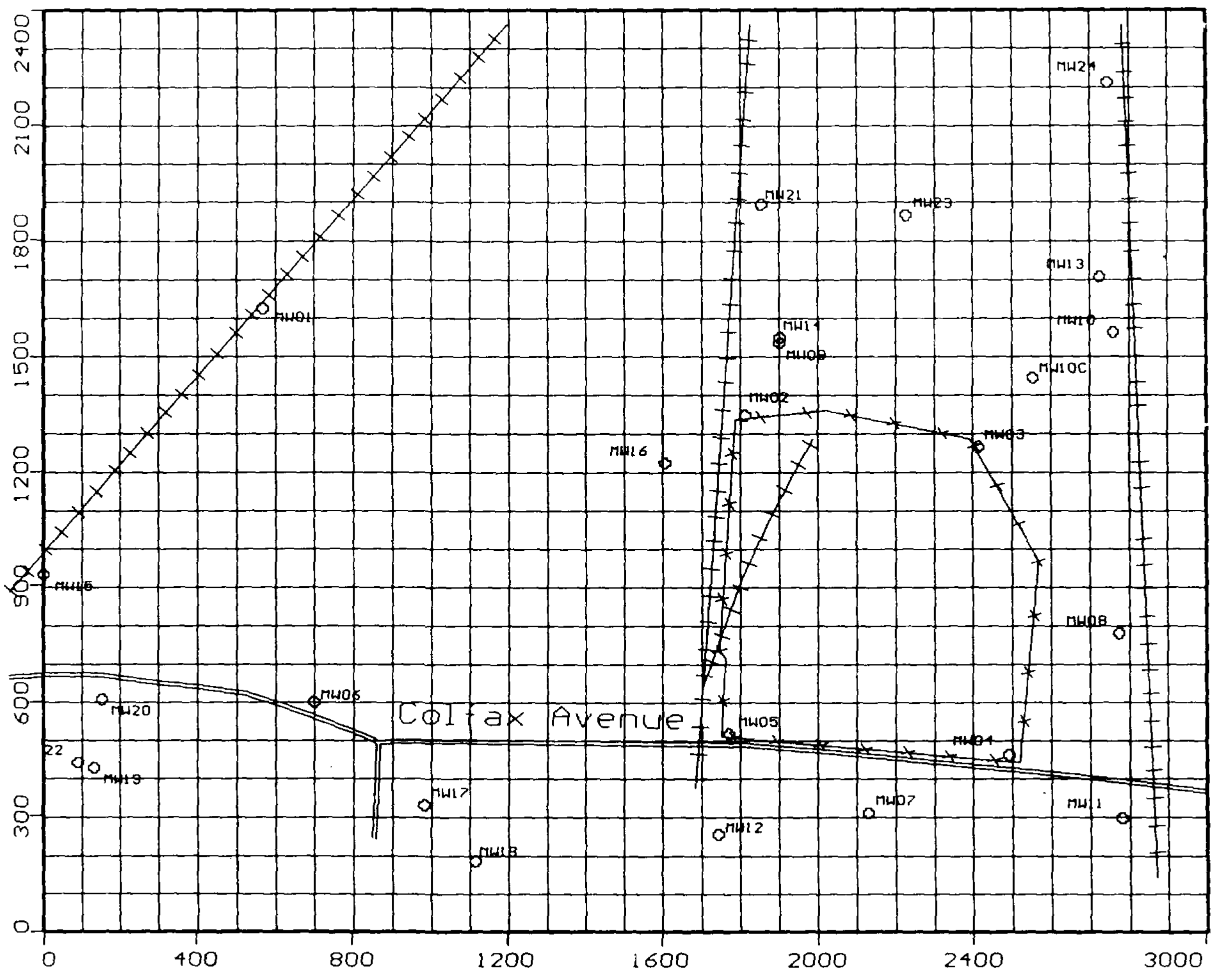
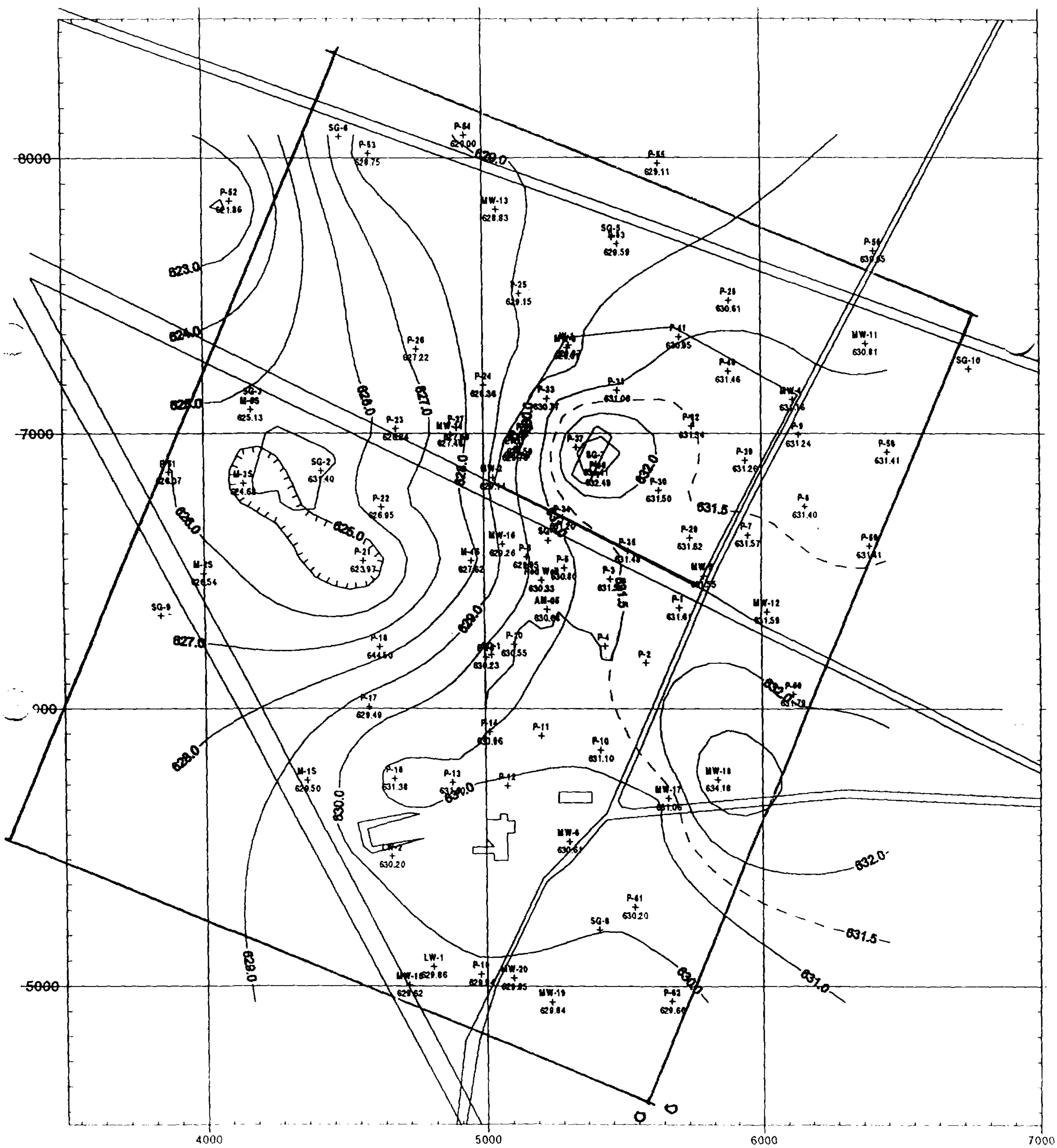


Figure 1. Finite-Difference Grid Orientation for Modflow Model
ACS NPL Site RD/RA

Montgomery Watson – Wayne, PA Project: ACS NPL Site RD/RA Description: Modflow Grid Modeller: PGCS7 Extraction Trench 12 Jul 95	Visual MODFLOW v.1.10, (c) 1994 Waterloo Hydrogeologic Software NC: 30 NR: 24 NL: 1 Current Layer: 1

Figure 2. Watertable Contour Map from October 30, 1995 Water Levels
ACS NPL Site RD/RA



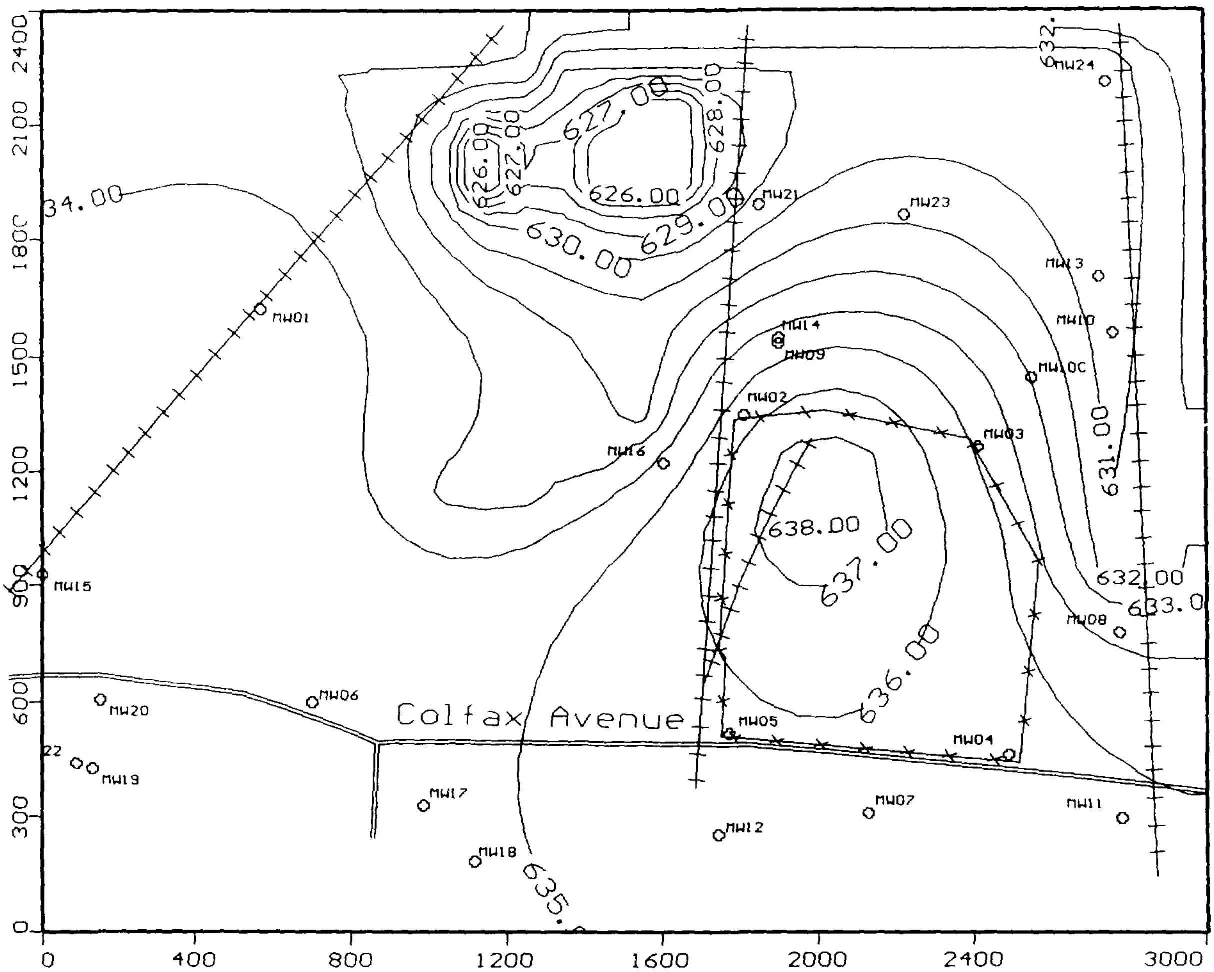


Figure 3. Modeled Baseline Watertable Contour Map
ACS NPL Site RD/RA

Montgomery Watson – Wayne, PA Project: ACS NPL Site RD/RA Description: Modeled Watertable Map Modeller: Baseline Model 12 Jul 95	Visual MODFLOW v.1.10, (c) 1994 Waterloo Hydrogeologic Software NC: 30 NR: 24 NL: 1 Current Layer: 1

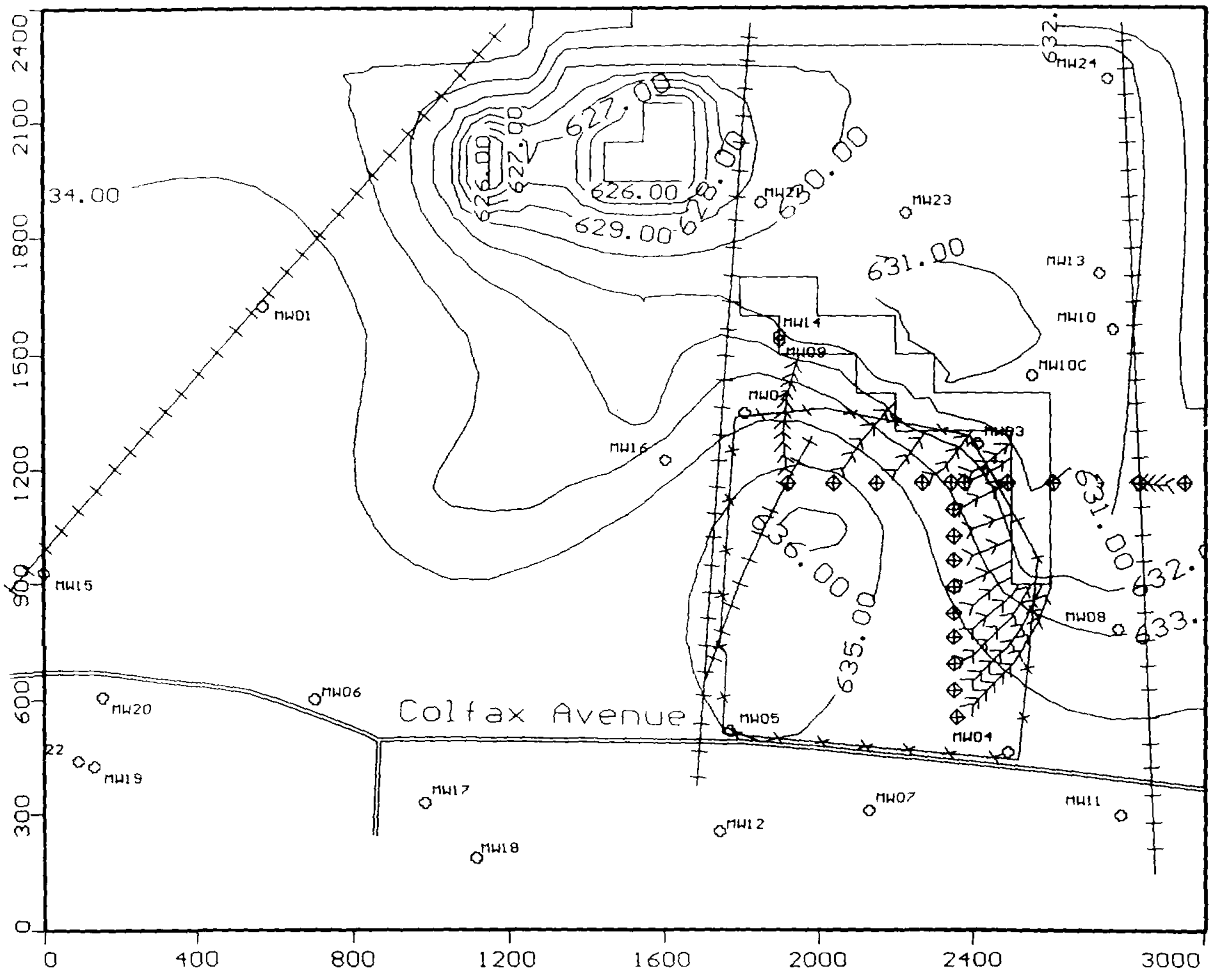


Figure 4. Modeled Groundwater Capture in the Upper Aquifer, with Extraction Trench
ACS NPL Site RD/RA

Montgomery Watson – Wayne, PA Project: ACS NPL Site RD/RA Description: Groundwater Capture Modeller: PGCS7 Extraction Trench 12 Dec 95	Visual MODFLOW v.1.10, (c) 1994 Waterloo Hydrogeologic Software NC: 30 NR: 24 NL: 1 Current Layer: 1

```
 The listing file output unit is  6
 The Basic Package input unit is  1
1                     U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL
0Basic Package translator - (c) 1994 Waterloo Hydrogeologic Software          PGCS7-V.BAS Mon Jul 10 23:29:01 1995
    1 LAYERS        24 ROWS        30 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS
0I/O UNITS:
 ELEMENT OF IUNIT:  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
         I/O UNIT: 11  0 13 14  0  0 17 18 19  0  0 22  0  0  0  0  0  0  0  0  0  0  0  0
0BAS1 -- BASIC MODEL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT  1
 ARRAYS RHS AND BUFF WILL SHARE MEMORY.
 START HEAD WILL BE SAVED
     6538 ELEMENTS IN X ARRAY ARE USED BY BAS
     6538 ELEMENTS OF X ARRAY USED OUT OF 5000000
0BCF2 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 2, 7/1/91 INPUT READ FROM UNIT 11
 TRANSIENT SIMULATION
 HEAD AT CELLS THAT CONVERT TO DRY= -0.10000E+31
 WETTING CAPABILITY IS NOT ACTIVE
      LAYER  AQUIFER TYPE
      ------------------
         1        1
     2161 ELEMENTS IN X ARRAY ARE USED BY BCF
     8699 ELEMENTS OF X ARRAY USED OUT OF 5000000
0DRN1 -- DRAIN PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 13
 MAXIMUM OF    15 DRAINS
       75 ELEMENTS IN X ARRAY ARE USED FOR DRAINS
     8774 ELEMENTS OF X ARRAY USED OUT OF 5000000
0RCH1 -- RECHARGE PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 18
 OPTION 1 -- RECHARGE TO TOP LAYER
      720 ELEMENTS OF X ARRAY USED FOR RECHARGE
     9494 ELEMENTS OF X ARRAY USED OUT OF 5000000
0RIV1 -- RIVER PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 14
 MAXIMUM OF    52 RIVER NODES
      312 ELEMENTS IN X ARRAY ARE USED FOR RIVERS
     9806 ELEMENTS OF X ARRAY USED OUT OF 5000000
0GHB1 -- GHB PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 17
 MAXIMUM OF   102 HEAD-DEPENDENT BOUNDARY NODES
      510 ELEMENTS IN X ARRAY ARE USED FOR HEAD-DEPENDENT BOUNDARIES
    10316 ELEMENTS OF X ARRAY USED OUT OF 5000000
0SIP1 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 19
 MAXIMUM OF  50 ITERATIONS ALLOWED FOR CLOSURE
   0 ITERATION PARAMETERS
     3090 ELEMENTS IN X ARRAY ARE USED BY SIP
    13406 ELEMENTS OF X ARRAY USED OUT OF 5000000
```

1Basic Package translator - (c) 1994 Waterloo Hydrogeologic Software PGCS7-V.BAS Mon Jul 10 23:29:01 1995
0

BOUNDARY ARRAY FOR LAYER 1 WILL BE READ ON UNIT 1 USING FORMAT: (40I2)

0AQUIFER HEAD WILL BE SET TO 1.00000E+30 AT ALL NO-FLOW NODES (IBOUND=0).
0

INITIAL HEAD FOR LAYER 1 WILL BE READ ON UNIT 1 USING FORMAT: (10G12.5)

0HEAD PRINT FORMAT IS FORMAT NUMBER 0 DRAWDOWN PRINT FORMAT IS FORMAT NUMBER 0
0HEADS WILL BE SAVED ON UNIT 30 DRAWDOWNS WILL BE SAVED ON UNIT 31
0OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
0

COLUMN TO ROW ANISOTROPY WILL BE READ ON UNIT 11 USING FORMAT: (10G11.4)

0 DELR = 100.0000
DELC = 100.0000

PRIMARY STORAGE COEF FOR LAYER 1 WILL BE READ ON UNIT 11 USING FORMAT: (10G11.4)

0

HYD. COND. ALONG ROWS FOR LAYER 1 WILL BE READ ON UNIT 11 USING FORMAT: (10G11.4)

0 BOTTOM = 620.0000 FOR LAYER 1
0

SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE

0 MAXIMUM ITERATIONS ALLOWED FOR CLOSURE = 50
ACCELERATION PARAMETER = 1.0000
HEAD CHANGE CRITERION FOR CLOSURE = 0.50000E-02
SIP HEAD CHANGE PRINTOUT INTERVAL = 10
CALCULATE ITERATION PARAMETERS FROM MODEL CALCULATED WSEED
STRESS PERIOD NO. 1, LENGTH = 20000.00

NUMBER OF TIME STEPS = 5

MULTIPLIER FOR DELT = 1.500

INITIAL TIME STEP SIZE = 1516.588

0

15 DRAINS

0

LAYER	ROW	COL	ELEVATION	CONDUCTANCE	DRAIN NO.
1	8	19	630.0	190.0	1
1	9	20	630.0	190.0	2
1	8	20	630.0	190.0	3
1	9	21	630.0	190.0	4
1	10	22	630.0	190.0	5
1	9	22	630.0	190.0	6
1	11	23	630.0	190.0	7

1	10	23	630.0	190.0	8
1	11	24	630.0	190.0	9
1	11	25	630.0	190.0	10
1	15	26	629.0	190.0	11
1	14	26	630.0	190.0	12
1	13	26	630.0	190.0	13
1	12	26	630.0	190.0	14
1	11	26	630.0	190.0	15

0

RECHARGE WILL BE READ ON UNIT 18 USING FORMAT: (15G11.4)

0

52 RIVER REACHES

0

LAYER	ROW	COL	STAGE	CONDUCTANCE	BOTTOM ELEVATION	RIVER REACH
1	2	1	633.0	1500.	627.0	1
1	2	2	633.0	1500.	627.0	2
1	2	3	633.0	1500.	627.0	3
1	2	4	633.0	1500.	627.0	4
1	2	5	633.0	1500.	627.0	5
1	2	6	633.0	1500.	627.0	6
1	2	7	633.0	1500.	627.0	7
1	2	8	633.0	1500.	627.0	8
1	2	9	633.0	1500.	627.0	9
1	2	10	633.0	1500.	627.0	10
1	13	11	632.0	500.0	628.0	11
1	2	11	633.0	1500.	627.0	12
1	13	12	632.0	500.0	628.0	13
1	2	12	633.0	1500.	627.0	14
1	13	13	632.0	500.0	628.0	15
1	2	13	633.0	1500.	627.0	16
1	12	14	632.0	500.0	628.0	17
1	2	14	630.0	1500.	627.0	18
1	12	15	632.0	500.0	628.0	19
1	2	15	630.0	1500.	627.0	20
1	11	16	631.0	500.0	628.0	21
1	10	16	631.0	500.0	628.0	22
1	9	16	631.0	500.0	628.0	23
1	8	16	631.0	500.0	628.0	24
1	2	16	630.0	1500.	627.0	25
1	2	17	630.0	1500.	627.0	26
1	2	18	630.0	1500.	627.0	27
1	2	19	630.0	1500.	627.0	28
1	2	20	630.0	1500.	627.0	29
1	2	21	630.0	1500.	627.0	30
1	2	22	630.0	1500.	627.0	31
1	2	23	630.0	1500.	627.0	32
1	2	24	630.0	1500.	627.0	33
1	2	25	630.0	1500.	627.0	34
1	2	26	630.0	1500.	627.0	35
1	2	27	630.0	1500.	627.0	36
1	15	28	631.0	1500.	627.0	37
1	14	28	630.9	1500.	627.0	38
1	13	28	630.8	1500.	627.0	39
1	12	28	630.7	1500.	627.0	40
1	11	28	630.6	1500.	627.0	41
1	10	28	630.5	1500.	627.0	42
1	9	28	630.4	1500.	627.0	43
1	8	28	630.3	1500.	627.0	44
1	7	28	630.2	1500.	627.0	45
1	6	28	630.1	1500.	627.0	46

1	5	28	630.0	1500.	627.0	47
1	4	28	630.0	1500.	627.0	48
1	3	28	630.0	1500.	627.0	49
1	2	28	630.0	1500.	627.0	50
1	15	29	631.5	1500.	627.0	51
1	15	30	632.0	1500.	627.0	52

0

102 HEAD-DEPENDENT BOUNDARY NODES

0

LAYER	ROW	COL	ELEVATION	CONDUCTANCE	BOUND NO.
1	24	1	634.0	25.00	1
1	23	1	634.0	25.00	2
1	22	1	634.0	25.00	3
1	21	1	634.0	25.00	4
1	20	1	634.0	25.00	5
1	19	1	634.0	25.00	6
1	18	1	634.0	25.00	7
1	17	1	634.0	25.00	8
1	16	1	634.0	25.00	9
1	15	1	634.0	25.00	10
1	14	1	634.0	25.00	11
1	13	1	634.0	25.00	12
1	12	1	634.0	25.00	13
1	11	1	634.0	25.00	14
1	10	1	634.0	25.00	15
1	9	1	634.0	25.00	16
1	8	1	634.0	25.00	17
1	7	1	634.0	25.00	18
1	6	1	634.0	25.00	19
1	5	1	634.0	25.00	20
1	4	1	634.0	25.00	21
1	3	1	634.0	25.00	22
1	1	1	634.0	25.00	23
1	24	2	634.0	25.00	24
1	1	2	634.0	25.00	25
1	24	3	634.0	25.00	26
1	1	3	634.0	25.00	27
1	24	4	634.0	25.00	28
1	1	4	634.0	25.00	29
1	24	5	634.0	25.00	30
1	1	5	634.0	25.00	31
1	24	6	634.0	25.00	32
1	1	6	634.0	25.00	33
1	24	7	634.0	25.00	34
1	1	7	634.0	25.00	35
1	24	8	634.0	25.00	36
1	1	8	634.0	25.00	37
1	24	9	634.0	25.00	38
1	1	9	634.0	25.00	39
1	24	10	634.0	25.00	40
1	1	10	634.0	25.00	41
1	24	11	634.0	25.00	42
1	1	11	634.0	25.00	43
1	24	12	634.0	25.00	44
1	1	12	634.0	25.00	45
1	24	13	634.0	25.00	46
1	1	13	634.0	25.00	47
1	24	14	634.0	25.00	48
1	1	14	634.0	25.00	49
1	24	15	634.1	25.00	50
1	1	15	634.0	25.00	51
1	24	16	634.2	25.00	52
1	1	16	634.0	25.00	53

1	24	17	634.4	25.00	54
1	1	17	634.0	25.00	55
1	24	18	634.5	25.00	56
1	1	18	634.0	25.00	57
1	24	19	634.7	25.00	58
1	1	19	634.0	25.00	59
1	24	20	634.8	25.00	60
1	1	20	634.0	25.00	61
1	24	21	635.0	25.00	62
1	1	21	634.0	25.00	63
1	24	22	635.0	25.00	64
1	1	22	634.0	25.00	65
1	24	23	635.0	25.00	66
1	1	23	634.0	25.00	67
1	24	24	635.0	25.00	68
1	1	24	634.0	25.00	69
1	24	25	635.0	25.00	70
1	1	25	634.0	25.00	71
1	24	26	635.0	25.00	72
1	1	26	634.0	25.00	73
1	24	27	635.0	25.00	74
1	1	27	634.0	25.00	75
1	24	28	635.0	25.00	76
1	1	28	634.0	25.00	77
1	24	29	635.0	25.00	78
1	1	29	634.0	25.00	79
1	24	30	635.0	25.00	80
1	23	30	635.0	25.00	81
1	22	30	635.0	25.00	82
1	21	30	635.0	25.00	83
1	20	30	635.0	25.00	84
1	19	30	635.0	25.00	85
1	18	30	635.0	25.00	86
1	17	30	635.0	25.00	87
1	16	30	635.0	25.00	88
1	14	30	634.0	25.00	89
1	13	30	634.0	25.00	90
1	12	30	634.0	25.00	91
1	11	30	634.0	25.00	92
1	10	30	634.0	25.00	93
1	9	30	633.0	25.00	94
1	8	30	633.0	25.00	95
1	7	30	633.0	25.00	96
1	6	30	633.0	25.00	97
1	5	30	633.0	25.00	98
1	4	30	633.0	25.00	99
1	3	30	633.0	25.00	100
1	2	30	633.0	25.00	101
1	1	30	633.0	25.00	102

```
0AVERAGE SEED = 0.00264484
 MINIMUM SEED = 0.00209141
0
   10 ITERATION PARAMETERS CALCULATED FROM AVERAGE SEED:

          0.0000000E+00  0.4828699E+00  0.7325764E+00  0.8617072E+00  0.9284846E+00  0.9630172E+00
          0.9808751E+00  0.9901099E+00  0.9948856E+00  0.9973552E+00
0
    11 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  1
0HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0     CELL-BY-CELL FLOW TERM FLAG = 0
0OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 --------------------------------
     0         0       0       0
```

```
 CALIBRATION PACKAGE OUTPUT
 CALIBRATION OUTPUT POINTS
 -----------------
    10 ITERATIONS FOR TIME STEP   2 IN STRESS PERIOD  1
0HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0     CELL-BY-CELL FLOW TERM FLAG = 0
0OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     0         0       0       0
 CALIBRATION PACKAGE OUTPUT
 CALIBRATION OUTPUT POINTS
 -----------------
     4 ITERATIONS FOR TIME STEP   3 IN STRESS PERIOD  1
0HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0     CELL-BY-CELL FLOW TERM FLAG = 0
0OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     0         0       0       0
 CALIBRATION PACKAGE OUTPUT
 CALIBRATION OUTPUT POINTS
 -----------------
     1 ITERATIONS FOR TIME STEP   4 IN STRESS PERIOD  1
 EAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0     CELL-BY-CELL FLOW TERM FLAG = 0
0OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     0         0       0       0
 CALIBRATION PACKAGE OUTPUT
 CALIBRATION OUTPUT POINTS
 -----------------
     1 ITERATIONS FOR TIME STEP   5 IN STRESS PERIOD  1
0MAXIMUM HEAD CHANGE FOR EACH ITERATION:
0 HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW
 ------------------------------------------------------------------------------------------------------------------------------
  -0.1546E-02 (  1,  6, 23)
0
0HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0     CELL-BY-CELL FLOW TERM FLAG = 0
0OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     0         0       1       1
  EAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP  5, STRESS PERIOD  1
0DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP  5, STRESS PERIOD  1
0


                              VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD  1
                              ---------------------------------------------------------------------------
0              CUMULATIVE VOLUMES      L**3                              RATES FOR THIS TIME STEP      L**3/T
               ------------------                                        ------------------------

                    IN:                                                           IN:
                    ---                                                           ---
                      STORAGE =   0.10729E+07                                       STORAGE =   0.93726E-01
                CONSTANT HEAD =   0.00000E+00                                 CONSTANT HEAD =   0.00000E+00
                       DRAINS =   0.00000E+00                                        DRAINS =   0.00000E+00
                     RECHARGE =   0.10729E+09                                      RECHARGE =     5364.4
                RIVER LEAKAGE =   0.58662E+07                                 RIVER LEAKAGE =     293.43
              HEAD DEP BOUNDS =   0.33777E+08                               HEAD DEP BOUNDS =     1693.4
0                    TOTAL IN =   0.14800E+09                                      TOTAL IN =     7351.3
```

```
0                   OUT:                                                        OUT:
                    ----                                                        ----
                       STORAGE =     882.11                                        STORAGE =   0.25836E-03
                 CONSTANT HEAD =   0.20870E+08                               CONSTANT HEAD =    1042.7
                        DRAINS =   0.48050E+08                                      DRAINS =    2382.4
                      RECHARGE =   0.00000E+00                                    RECHARGE =   0.00000E+00
                 RIVER LEAKAGE =   0.73133E+08                               RIVER LEAKAGE =    3641.1
               HEAD DEP BOUNDS =   0.64893E+07                             HEAD DEP BOUNDS =    318.83
0                    TOTAL OUT =   0.14854E+09                                   TOTAL OUT =    7385.0
0                     IN - OUT =  -0.53883E+06                                    IN - OUT =   -33.749
0         PERCENT DISCREPANCY =                -0.36                  PERCENT DISCREPANCY =                -0.4


0


          TIME SUMMARY AT END OF TIME STEP  5 IN STRESS PERIOD  1
                                  SECONDS       MINUTES        HOURS          DAYS          YEARS
                               -----------------------------------------------------------------------
      TIME STEP LENGTH          0.663355E+09  0.110559E+08   184265.        7677.72        21.0205
    STRESS PERIOD TIME          0.172800E+10  0.288000E+08   480000.        20000.0        54.7570
 TOTAL SIMULATION TIME          0.172800E+10  0.288000E+08   480000.        20000.0        54.7570

 CALIBRATION PACKAGE OUTPUT
 CALIBRATION OUTPUT POINTS
 -----------------
```

Appendix Y

Groundwater Model

AOS Risk Assessment

U.S.G.S Modflow model (Modflow) was used to simulate the groundwater flow system in the upper aquifer at the American Chemical Service NPL Site. Modflow is a three-dimensional finite-difference groundwater flow model developed by the U.S. Geological Survey. The model simulates groundwater flow within aquifers using a block-centered finite-difference approach. Multiple layers can be simulated as confined, unconfined, or a combination of both. The model can simulate external stresses including: flow to wells, areal recharge, evapotranspiration, flow to drains, flow through riverbeds, and general-head boundary conditions.

The version used for this report was compiled by S.S. Papadopulos & Associates for use with the MT3D method of characteristics solute transport simulation. Abstracts from the Modflow and MT3D model documentation are attached. The following items are also attached following this summary of the modeling procedure:

- Table summarizing input variables for the modeling.
- Figure showing Finite Difference Grid and Node Assignments
- Contour plots of the simulated water table under current conditions, and future conditions, assuming landfill closure, and closure of the ACS Firepond.
- Block diagrams of the current and future water table simulations
- Solute transport simulation results for 10 years, 20 years and 30 years to predict effects of Griffith municipal landfill in upper aquifer.
- Modflow input files for Current Conditions Simulation
- Modflow input files for Future Conditions Simulation
- MT3D input files for simulating 30 years of solute transport from the Griffith Municipal Landfill.

MODEL PARAMETERS

Modeling in this implementation was limited to the upper aquifer which is effectively isolated from lower aquifer by the clay confining layer found beneath the upper aquifer across the whole site. A single consistent set of time and space units are required for the model. The units selected for this implementation were "feet" for length units and "days" for the time unit. The following parameters resulted. Grid spacing, aquifer thickness, and watertable elevation were reported in feet. Hydraulic conductivity units were in feet per day; transmissivity units were in feet-squared per day. Volumes of discharge and recharge were reported in cubic feet per day. The Strongly Implicit Procedure (SIP) module used to solve model.

A 30 column, 24 row finite difference grid, with 100-foot grid spacing was used for the simulation. Input variables are used in the model to define the: 1) aquifer geometry, 2) boundary conditions, 3) hydraulic characteristics of the aquifer, and 4) recharge/discharge interactions with the atmosphere and surface water bodies. The use of each of these groups of input parameters is discussed below. The attached figure, "Finite Difference Grid, Model Node Assignments," displays the orientation of the model over the modeled area, and indicates the boundary conditions used.

Aquifer Geometry

Aquifer thickness is variable because the a water table aquifer is being modeled. The base of the aquifer is assumed to be 620 feet msl. The water table elevation is variable across the Site, at 630 to 634 feet msl in the ACS facility, to less than 625 feet in vicinity of the municipal landfill where de-watering occurs continuously.

Boundary Conditions

The General Head Boundary (GHB) module was used to simulate the boundary conditions surrounding the site. GHB entries were made for each of the exterior nodes of the model. The "head" specified for each was the average groundwater elevation observed along that boundary during the RI. The conductivity value was selected to represent the transmissivity of the aquifer.

Hydraulic Properties

Aquifer characteristics are required for each layer of the model. These include: specific yield (storativity), hydraulic conductivity, and transmissivity, vertical hydraulic conductivity between model layers.

Specific Yield for the upper aquifer was assigned to be SF1 = 0.25. Since the aquifer being simulated is unconfined, it was not necessary to assign a storativity value.

Hydraulic Conductivity. Based on baildown tests conducted at the Phase I and II monitoring wells, it was determined that the hydraulic conductivity ranges from 2.4 to 24 feet/day ($8.5x10^{-4}$ to $8.5x10^{-3}$ cm/sec) from west to east across the site. The model calculated the transmissivity for each node, by multiplying the value by the saturated thickness, calculated as the difference between the water table elevation and elevation of the bottom of the layer. The bottom elevation (BOT-1) was assigned as 620 feet in the BCF input file.

Recharge/Discharge

Recharge is both lateral and vertical. Lateral recharge occurs to the upper aquifer from north and east of the Site. For the simulation, lateral recharge is controlled by the General Head Boundary assignments in column 30 and row 24.

Areal recharge was applied on the basis of 6 inches per year infiltration (0.00137 feet/day), in the RCH module. Areal recharge was not applied to discharge areas, including areas of wetland observed at the site. The primary recharge occurred across the ACS facility, where there is little relief and no vegetation to promote runoff and evapotranspiration. Storm sewers drain approximately one-third of the ACS compound directly into the fire pond. The area drained is approximately 50 times greater than the fire pond surface area, so the recharge to the pond was calculated to be 50 times the annual infiltration rate.

Primary discharge from the upper aquifer occurs toward the landfill de-watering area in the southwest, and toward the drainage ditch which runs to the northwest and west of the site. These were simulated by establishing "river nodes" with assigned head values in the RIV module. Locations are shown on the attached Figure.

MODEL IMPLEMENTATION

Existing Conditions Simulation

The model was implemented with the hydraulic data developed in the Remedial Investigation of the site. Initially the model was implemented to replicate the existing conditions at the site, with surface water discharge to the ACS Firepond and groundwater discharge to the excavation area in the Griffith Municipal Landfill. The input files are included in this appendix. The DOS extension for the files is "*.AC1". Upon obtaining a reasonable replication of the observed water table configuration, the model was used to predict the future water table configuration, assuming that the Griffith Landfill is closed, so upper aquifer de-watering is discontinued, and the ACS fire pond is no longer used to receive surface water run-off.

The aquifer permeability values used were derived by conducting baildown tests at most of the site monitoring wells. The results suggested that the hydraulic conductivity is an order of magnitude higher on the east side of the site than along the western boundary of the ACS facility. Grain-size analysis of aquifer samples indicated that the aquifer matrix was coarser grained at the wells along the eastern boundary. Groundwater flow modeling was used to history match water table configurations. It was found that the observed head distribution in the upper aquifer was most reasonably achieved in the simulation where hydraulic conductivity values were 10x lower on the western side of the site.

The model was calibrated to known water table elevations, measured at approximately 50 points across the site, including surface water locations, measured at four different times throughout approximately one year. Sensitivity analysis was conducted with 1) aerial recharge by infiltrating precipitation and 2) hydraulic conductivity.

Average annual precipitation in northwestern Indiana is 44 inches. Simulations were run with assumed infiltration of 4 to 20 inches (10 to 50 percent). Infiltration amounts from 4 to 12 inches gave results which were consistent with field observations. Even 20 inches provided reasonable results. In otherwords, the model was relatively insensitive to variations in total infiltration amounts.

The use of lower hydraulic conductivity values caused significant deviations from the observed water table heads. However, doubling and quadrupling the hydraulic conductivity had relatively little effect on the water table distribution. Six inches of annual infiltration, representing approximately 15 percent of the annual precipitation was selected as representative of the site conditions.

The major control on groundwater flow regime (and associated head values) appears to be the steep gradient and interaction between recharge at ACS and de-watering in the landfill area.

Future Conditions Simulation

Three changes were made to the current condition (*.AC1) input files to create the future condition (*.AC3):

- the "drains" which represent the de-watering at the landfill were removed;
- the high level of recharge to the fire pond was eliminated; and
- Infiltration was reduced by a factor of 10 in the Off-Site Containment area, because it is assumed that the area will be remediated and capped.

The groundwater flow simulation was run for 30 years, for use in the solute transport simulation.

SOLUTE TRANSPORT SIMULATION

Benzene was selected as the source of contamination to model. The concentration of benzene observed in the landfill ranged from 2 to 6 ug/L. A value was 5 ug/L was assigned for the entire landfill area.

The future condition water table results (*.AC3 input files) were used for the advection for the transport simulation.

Longitudinal dispersion coefficient was assigned a value of D_l = 2 feet. Transverse and vertical dispersion coefficients of $D_t = D_v = 0.4$ were used. Retardation coefficients were calculated for the upper and lower aquifer in the RI Report, Section 6 (Table 6-2 and 6-4). The value derived was $R_f = 2.47$, based on aquifer porosity of 0.25, bulk density of 1.8, and a distribution coefficient of 0.204.

SIMULATION RESULTS

The groundwater modeling shows that closure of the landfill and ACS fire pond will result in significantly reduced hydraulic gradients, but in no major change in groundwater flow paths. The groundwater will still flow generally from the northeast, beneath the site and discharge at the ditch cut through the wetlands west of the Site.

In the current condition groundwater flow regime, all the groundwater flowing beneath the landfill, discharges to the de-watering excavations. In the future scenario, when the de-watering is discontinued, the drainage ditch will resume its function and groundwater will continue to discharge to the east.

The solute transport model shows that the the benzene level (and other landfill constituents) will migrate slowly towards the west. The upper aquifer surrounding the landfill will not be affected by leaking leachate.

GROUNDWATER MODEL DOCUMENTATION ABSTRACTS

Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A1

A MODULAR THREE-DIMENSIONAL FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

By Michael G. McDonald and
Arlen W. Harbaugh

This chapter supersedes U.S. Geological
Survey Open-File Report 83–875

Book 6

MODELING TECHNIQUES

A MODULAR THREE-DIMENSIONAL FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

By Michael G. McDonald and Arlen W. Harbaugh

ABSTRACT

This report presents a finite-difference model and its associated modular computer program. The model simulates flow in three dimensions. The report includes detailed explanations of physical and mathematical concepts on which the model is based and an explanation of how those concepts are incorporated in the modular structure of the computer program. The modular structure consists of a Main Program and a series of highly independent subroutines called "modules." The modules are grouped into "packages." Each package deals with a specific feature of the hydrologic system which is to be simulated, such as flow from rivers or flow into drains, or with a specific method of solving linear equations which describe the flow system, such as the Strongly Implicit Procedure or Slice-Successive Overrelaxation.

The division of the program into modules permits the user to examine specific hydrologic features of the model independently. This also facilitates development of additional capabilities because new packages can be added to the program without modifying the existing packages. The input and output systems of the computer program are also designed to permit maximum flexibility.

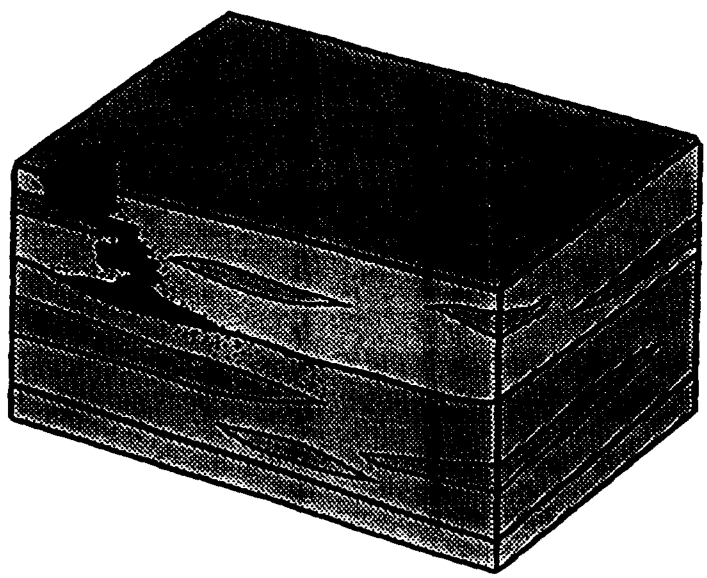
Ground-water flow within the aquifer is simulated using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of confined and unconfined. Flow associated with external stresses, such as wells, areal recharge, evapotranspiration, drains, and streams, can also be simulated. The finite-difference equations can be solved using either the Strongly Implicit Procedure or Slice-Successive Overrelaxation.

The program is written in FORTRAN 77 and will run without modification on most computers that have a FORTRAN 77 compiler. For each program module, this report includes a narrative description, a flow chart, a list of variables, and a module listing.

MT3D

a modular three-dimensional transport model

User's Manual



first edition 10/17/90
first revision 02/15/91

S.S. Papadopulos & Associates, Inc.

PREFACE

This document describes the theory and application of MT3D: a modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions in groundwater systems. It includes four computer disks containing the MT3D source code, example data sets, post-processing programs, and a flow model to be used in conjunction with MT3D. A supplemental document which contains a complete listing of the MT3D source code is available if there is a need to verify the source code included in the computer disk.

The documentation for the MT3D program has been funded in part by the United States Environmental Protection Agency. However, the funding does not constitute endorsement or recommendation by the United States Environmental Protection Agency for the use of MT3D or any commercial products mentioned in the document.

To report any error in the MT3D program or to inquire about future upgrades, please call or write to

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Abstract

mt3d: a modular three-dimensional transport model

This documentation describes the theory and application of a modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions of dissolved constituents in groundwater systems. The model program, referred to as MT3D, uses a modular structure similar to that implemented in MODFLOW, the U. S. Geological Survey modular three-dimensional finite-difference groundwater flow model (McDonald and Harbaugh, 1988). This modular structure makes it possible to simulate advection, dispersion, sink/source mixing, and chemical reactions independently without reserving computer memory space for unused options. New transport processes and options can be added to the model readily without having to modify the existing code.

The MT3D transport model uses a mixed Eulerian-Lagrangian approach to the solution of the three-dimensional advective-dispersive-reactive equation, in three basic options: the method of characteristics (referred to as MOC), the modified method of characteristics (referred to as MMOC), and a hybrid of these two methods (referred to as HMOC). This approach combines the strength of the method of characteristics for eliminating numerical dispersion and the computational efficiency of the modified method of characteristics. The availability of both MOC and MMOC options, and their selective use based on an automatic adaptive procedure under the HMOC option, make MT3D uniquely suitable for a wide range of field problems.

The MT3D transport model is intended to be used in conjunction with any block-centered finite-difference flow model such as MODFLOW and is based on the assumption that changes in the concentration field will not affect the flow field measurably. This allows the user to construct and calibrate a flow model independently. MT3D retrieves the hydraulic heads and the various flow and sink/source terms saved by the flow model, automatically incorporating the specified hydrologic boundary conditions. Currently, MT3D accommodates the following spatial discretization capabilities and transport boundary conditions: (1) confined, unconfined or variably confined/unconfined aquifer layers; (2) inclined model layers and variable cell thickness within the same layer; (3) specified concentration or mass flux boundaries; and (4) the solute transport effects of external sources and sinks such as wells, drains, rivers, areal recharge and evapotranspiration.

TABLE AND FIGURES

Table 1.
Summary of Input Variables
Upper Aquifer Groundwater Model
ACS NPL Site

The following are the input parameters for the Modflow Implementation of the upper aquifer at the ACS NPL Site. The general conductions used for all simulations are listed first. These are followed by a listing of the model parameters changed to simulate future conditions, and then input variables for the solute transport simulation.

Single layer, 30 column, 24 row finite difference grid. Uniform grid spacing = 100 foot.

Time Units = days, Length Units = feet

Boundary Conditions

- General Head Boundary conditions provide regional water table elevations of 635 feet msl in northeast, to 633 feet msl along south and west boundary, 635 to 634 feet msl along eastern boundary, and 635 to 633 feet msl along northern boundary.

- Groundwater elevation is essentially controlled by discharge to the creek on the northwest (column 28) and west sides (row 2).

Aquifer Properties

Specific yield/storage coefficient set as 0.25
Hydraulic conductivity range
2.4 to 24 ft/day (8.5×10^{-4} to 8.5×10^{-3} cm/sec)

Aquifer thickness calculated within model

- Top elevation from head-value for node
- Bottom elevation set at 620 ft msl

Discharge Areas

- De-watering at Landfill Excavation
- The DRN module was used to simulate de-watering to 625 feet msl in the landfill de-watering area.
- Three river stretches set by RIV module
- Creek along row 3 between column 2 and 9, set to 630 ft msl
- Creek along row 2 between column 26 and 28, set to 630 ft msl
- Ditch along north boundary simulated setting column 28, rows 3 - 15 at levels from 630 to 631
- Ditch just west of Off-Site Containment Area set at 632 ft msl,based on staff gage SG-1 history.

Table 1. (continued)
Summary of Input Variables
Upper Aquifer Groundwater Model
ACS NPL Site

Recharge Areas

- GBH boundaries provide lateral recharge from northeast area.
- RCH module used to apply areal precipitation recharge
- Average annual precipitation for area = 44 inches/year
- Model calibrated assuming 15% infiltration (6 in/yr) ACS facility has no vegetation.
- Storm sewers from southeast drain into fire pond
- Drained area is about 50x the fire pond area.
  - Coefficient of 50 used for fire pond
  - Coefficient of 2 used for much of unvegetated area
  - Factor of 2 used in Off site area at internal drainage area north of Off-Site containment area.

Time step was 5 years to represent essentially steady-state conditions.

Strongly Implicit Procedure (SIP) module used to solve model.

FUTURE CONDITION SIMULATION

Three changes were made to the current condition (*.AC1) input files to create the future condition (*.AC3):

- the "drains" which represent the de-watering at the landfill were removed;
- the high level of recharge to the fire pond was eliminated; and
- Infiltration was reduced by a factor of 10 in the Off-Site Containment area, because it is assumed that the area will be remediated and capped.

The groundwater flow simulation was run for 30 years, for use in the solute transport simulation.

SOLUTE TRANSPORT SIMULATION

Source: 5 ug/L benzene for entire landfill area.

Advection was driven by future condition water table configuration, for 30 year simulation.

Dispersion: $D_l = 2.0$ feet
$D_t = 0.4$ feet
$D_v = 0.4$ feet

Retardation. Benzene retardation factor = 2.47

Finite Difference Grid, Model Node Assignments

Columns ---->

Rows ↓

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		0
3	0															2	2											1		0
4	0								4	4	4	2	4	4	2	2	2											1		0
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6	0							4	4	4	4	4	4	4	4													1		0
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11	0			4	4	4	4	4	4	4	4	4	4	4	4	1												1		0
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18	0																	5	5	5	5	5	5	5	5					0
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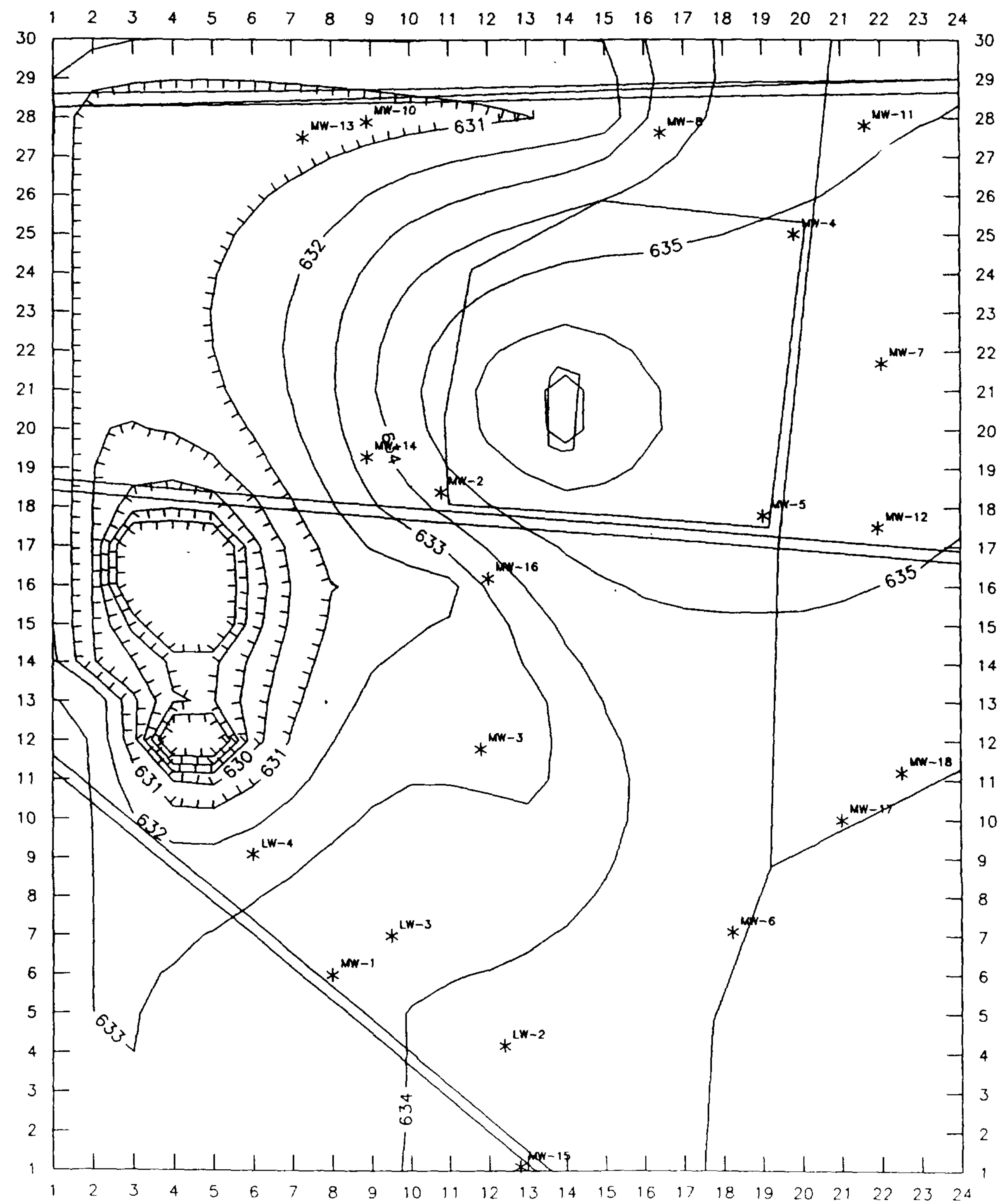
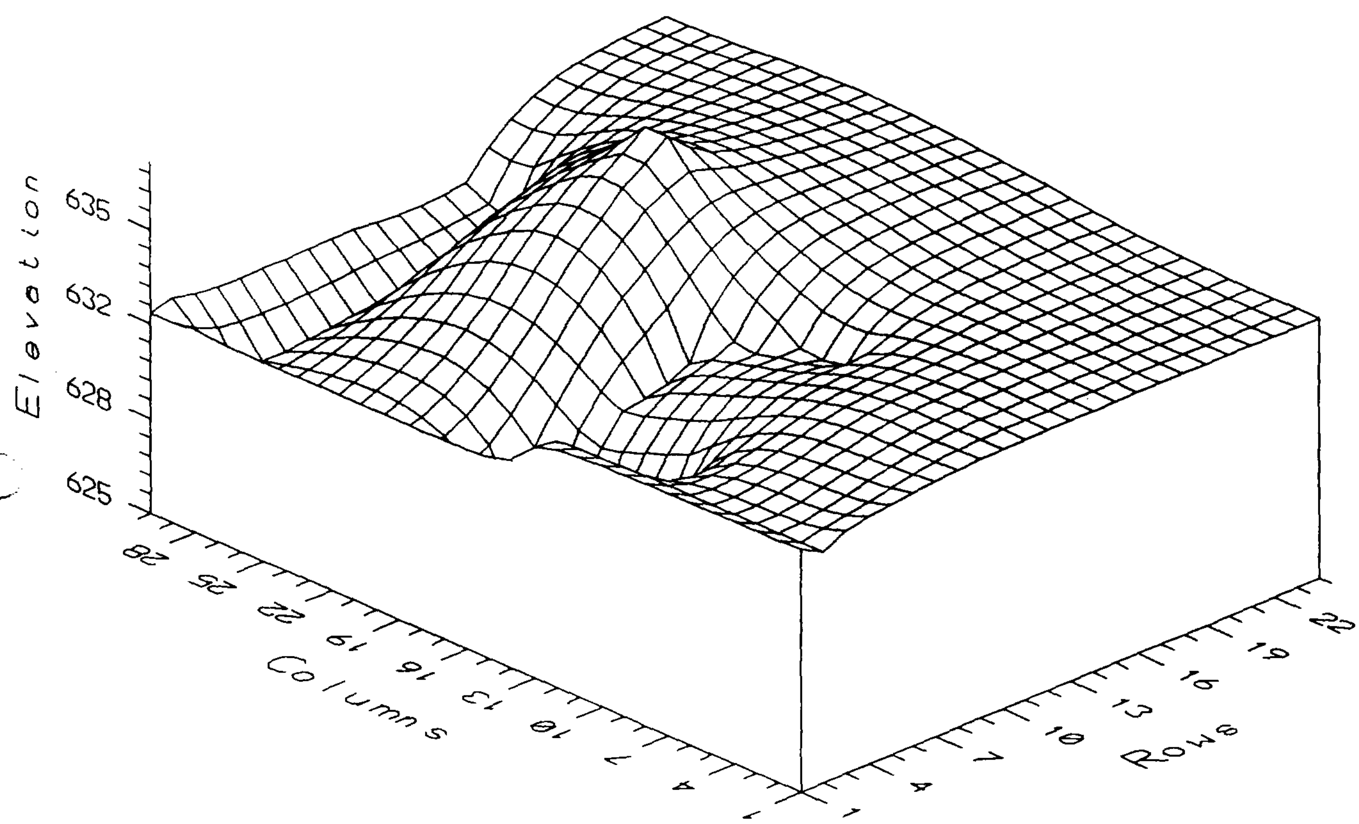
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Legend:

- 0 General Head Boundary Nodes
- 1 Creek Nodes
- 2 Landfill De-Watering Areas
- 3 ACS Fire Pond Nodes
- 4 Griffith Landfill Nodes
- 5 American Chemical Service Facility

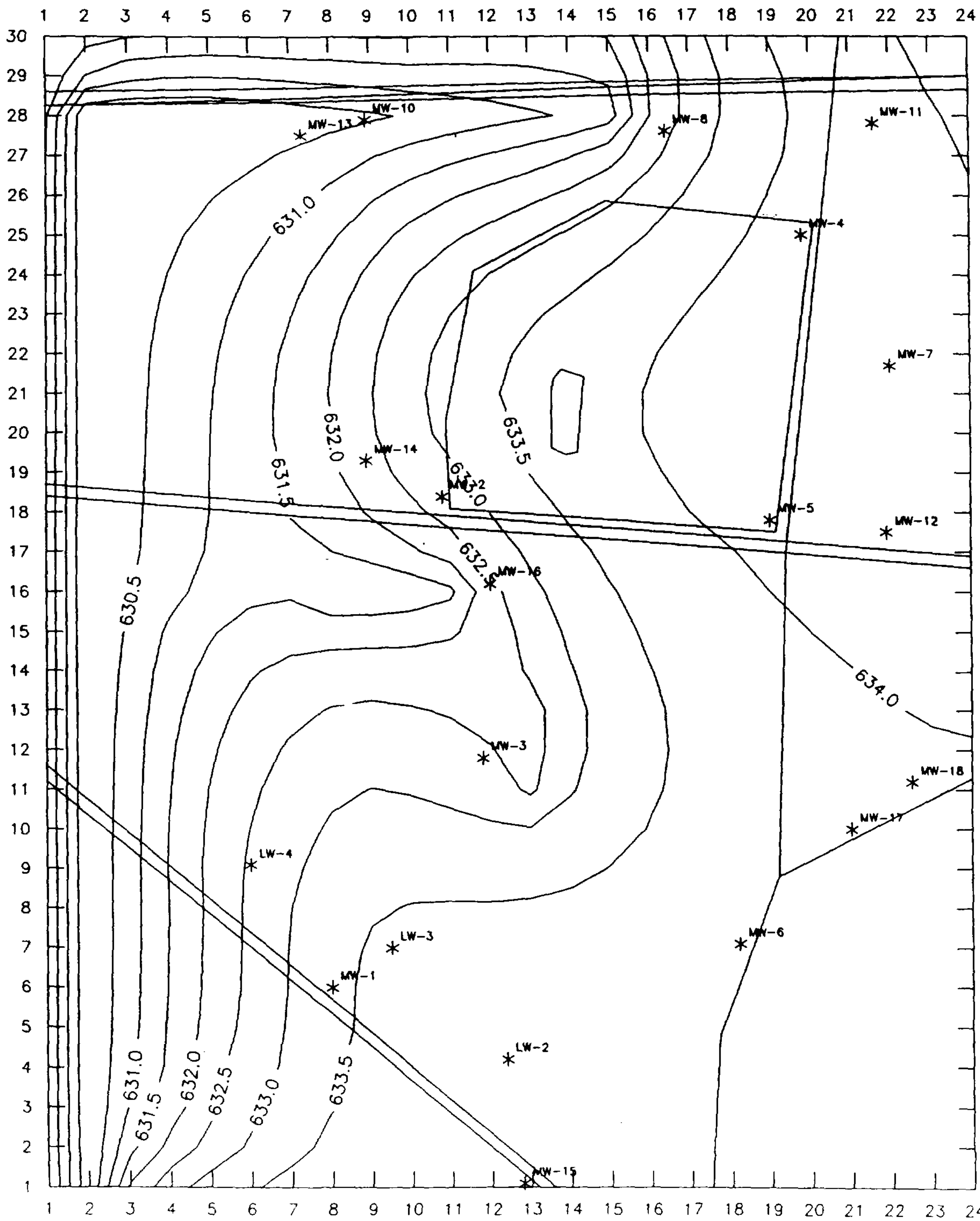
Modeled Water Table -- Current Conditions

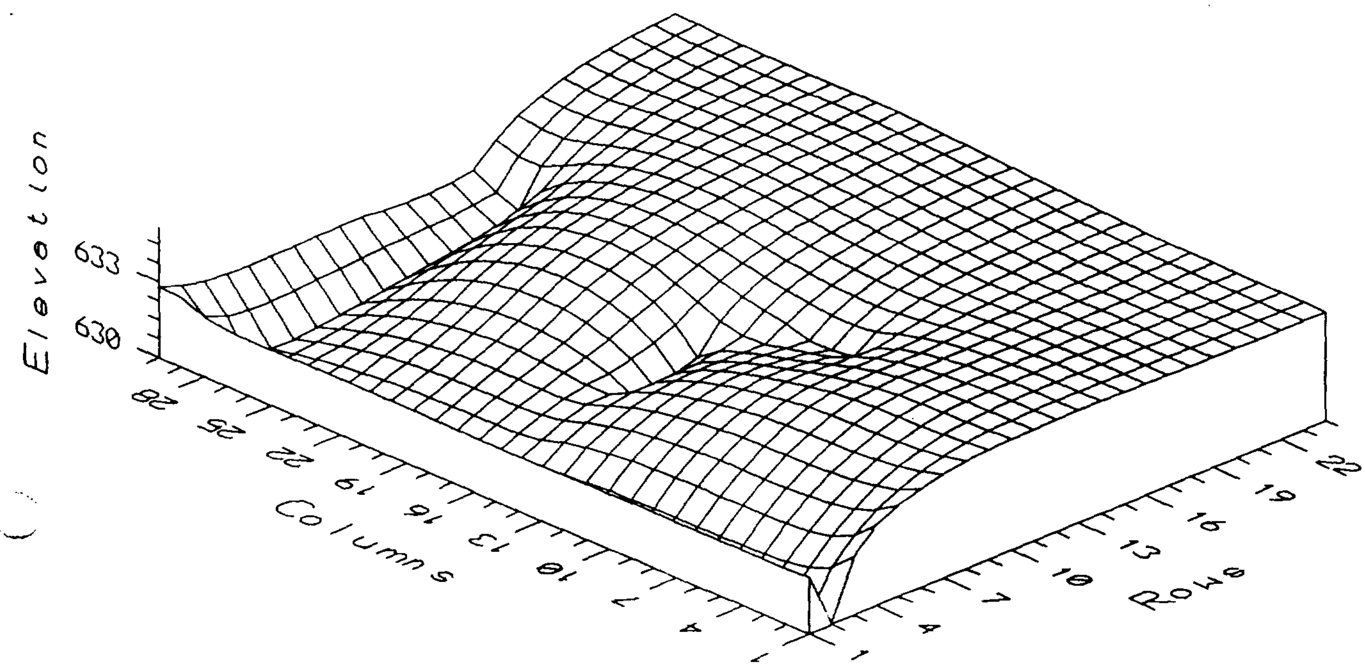




Modeled Existing Water Table

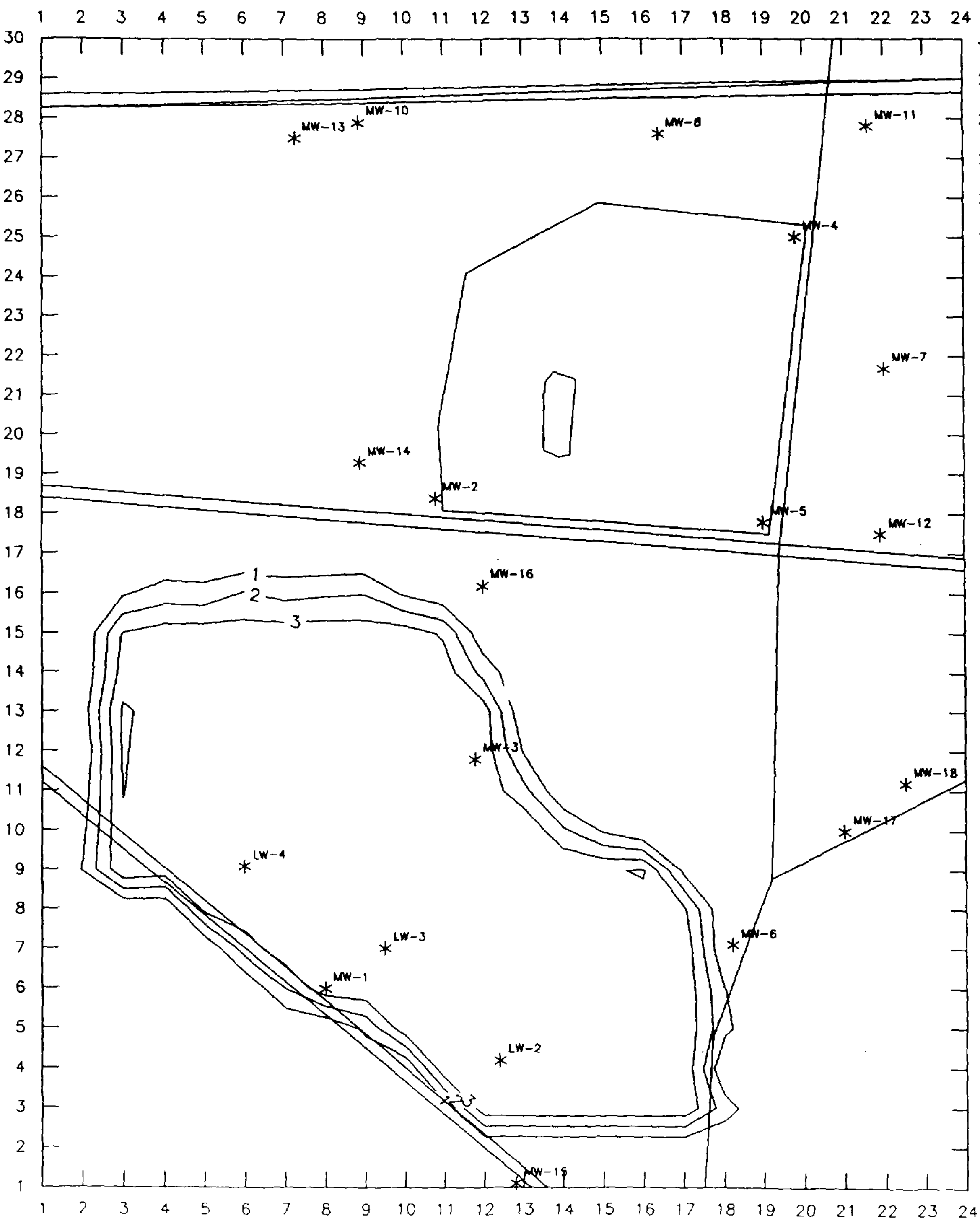
Future Conditions -- Landfill Closed, No Fire Pond



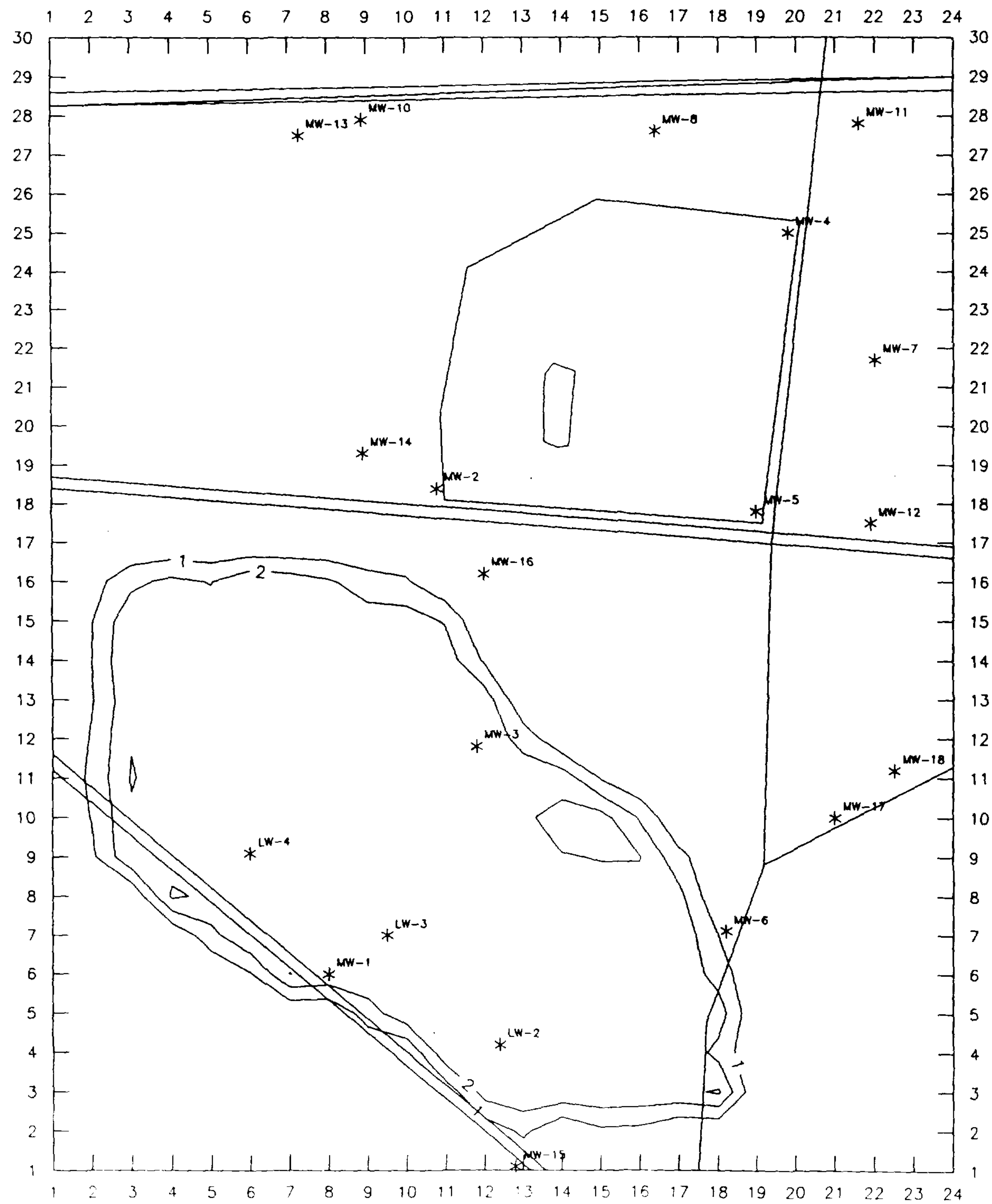


Modeled Future Water Table - Landfill Closed

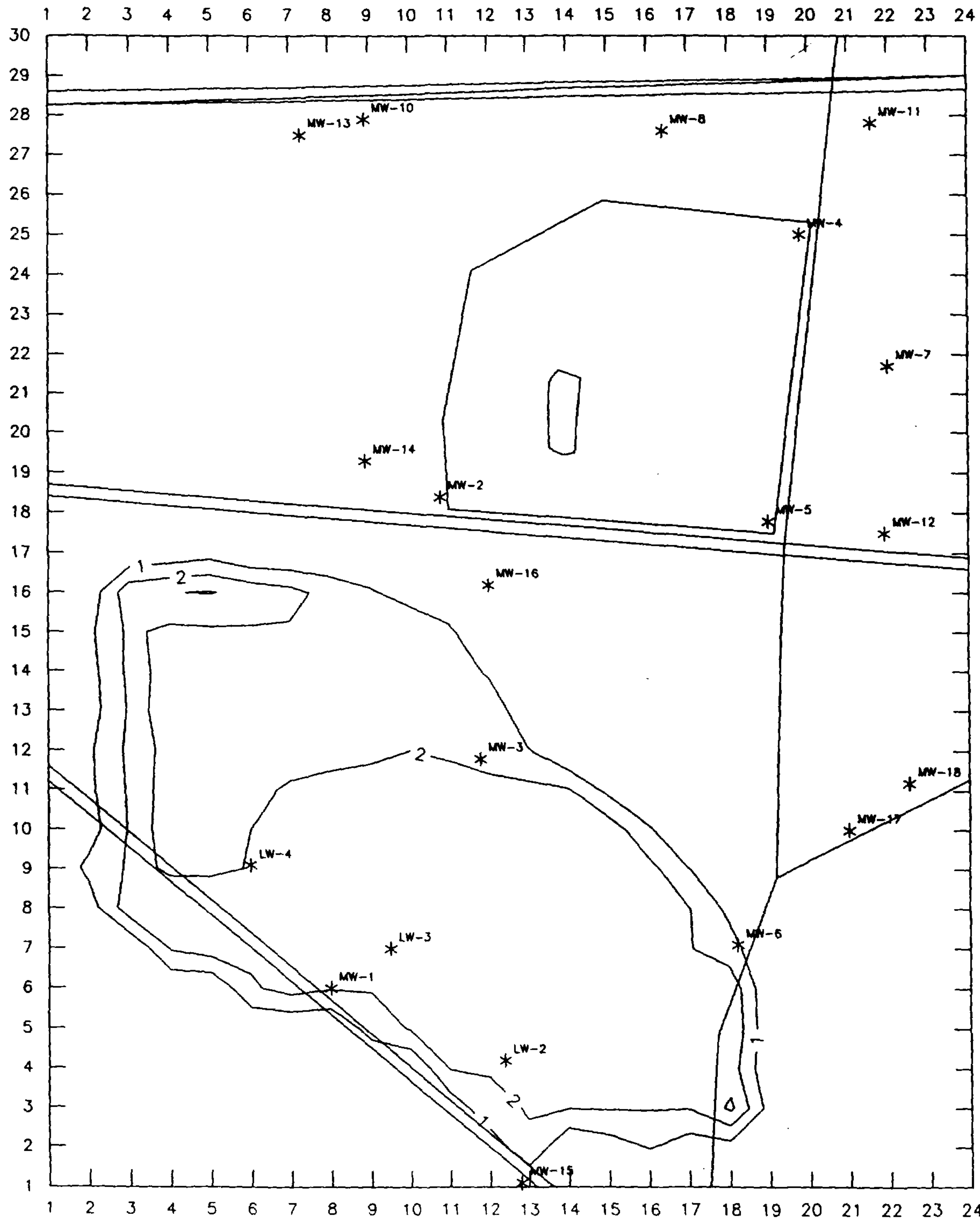
Modeled Benzene Concentration after 10 years



Modeled Benzene Concentration after 20 years



Modeled Benzene Concentration after 30 years



INPUT FILES
EXISTING CONDITION GROUNDWATER FLOW SYSTEM

EVP Reserv. RECH SIP SOR not used by Modflow

Wells BCF Drains RIV GHB OUTPUT NOT USED

```
BAS.AC1 -- K x 1 (2.4), 6 in/yr precip, creek 630 ft, Leach ditch 632 ft
landfill drains at 627 ft -- 5 year simulation
         1         24         30         1         4
11 0 13 14 0 0 17 18 19 0 0 22 0 0 0 0 0 0 0 24 0 0
         0          0                                     IAPART,ISTRT
         1          1  (30I2)                  3          IBOUND-1
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         1          1  (15F5.1)                4          IHEAD-1
6340 6310 6310 6310 6310 6310 6310 6310 6310 6300 6300 6300 6300 6300 6300
6300 6300 6300 6310 6310 6310 6310 6310 6310 6310 6310 6310 6310 6310 6300
6340 6301 6301 6301 6301 6301 6301 6300 6299 6298 6295 6294 6296 6298 6300
6301 6302 6302 6301 6300 6300 6300 6300 6300 6300 6300 6300 6300 6301 6301
6340 6301 6300 6300 6300 6300 6300 6300 6300 6295 6289 6284 6289 6295 6299
6270 6270 6304 6304 6304 6304 6304 6304 6303 6303 6302 6301 6300 6301 6301
6340 6303 6303 6303 6303 6303 6302 6301 6298 6292 6281 6217 6282 6293 6270
6270 6270 6307 6307 6307 6307 6307 6307 6306 6305 6304 6302 6300 6301 6302
6340 6304 6305 6305 6305 6305 6304 6303 6300 6294 6283 6210 6284 6295 6270
6270 6270 6309 6310 6310 6310 6310 6309 6308 6307 6305 6303 6300 6302 6302
6340 6305 6307 6307 6308 6307 6307 6305 6303 6299 6294 6289 6295 6301 6306
6309 6311 6312 6313 6313 6313 6312 6311 6310 6308 6306 6304 6301 6302 6303
6340 6307 6308 6309 6310 6310 6309 6309 6307 6305 6303 6302 6304 6307 6310
6313 6314 6315 6316 6316 6316 6315 6314 6312 6310 6307 6304 6301 6302 6303
6340 6308 6310 6311 6312 6312 6312 6312 6311 6310 6310 6310 6311 6313 6315
6316 6318 6319 6319 6319 6318 6317 6316 6314 6312 6309 6305 6301 6303 6304
6340 6309 6311 6313 6314 6314 6315 6315 6315 6315 6315 6315 6316 6317 6319
6320 6321 6322 6322 6322 6321 6320 6318 6316 6313 6310 6306 6301 6303 6304
6340 6311 6313 6314 6316 6317 6317 6318 6318 6319 6319 6320 6320 6321 6323
6324 6324 6325 6325 6325 6324 6323 6321 6318 6315 6311 6306 6301 6303 6305
6340 6312 6314 6316 6317 6319 6320 6321 6321 6322 6322 6323 6324 6325 6326
6327 6327 6328 6328 6328 6327 6325 6323 6320 6317 6312 6307 6301 6304 6306
6340 6313 6315 6317 6319 6320 6322 6323 6324 6325 6325 6326 6327 6328 6329
6330 6330 6331 6331 6331 6330 6328 6326 6323 6319 6314 6308 6301 6305 6307
6340 6313 6316 6318 6320 6322 6324 6325 6326 6327 6328 6329 6330 6331 6332
6332 6333 6334 6334 6334 6333 6331 6329 6326 6321 6316 6310 6301 6306 6308
```

all active cells

initial heads.

```
6340 6314 6317 6320 6322 6324 6325 6327 6328 6329 6330 6331 6332 6333 6334
6335 6335 6336 6336 6337 6336 6334 6331 6328 6324 6319 6312 6302 6307 6310
6340 6315 6318 6321 6323 6325 6327 6328 6329 6331 6332 6333 6334 6335 6336
6337 6337 6338 6338 6338 6338 6336 6334 6331 6328 6323 6316 6304 6312 6314
6340 6316 6319 6322 6324 6326 6328 6329 6331 6332 6333 6334 6335 6336 6337
6338 6339 6340 6340 6340 6339 6338 6337 6334 6331 6328 6323 6319 6320 6322
6340 6317 6320 6323 6325 6327 6329 6330 6332 6333 6334 6336 6337 6338 6339
6340 6341 6341 6342 6342 6341 6340 6339 6337 6335 6332 6330 6328 6327 6328
6340 6318 6321 6323 6326 6328 6329 6331 6333 6334 6335 6337 6338 6339 6340
6341 6342 6343 6343 6343 6343 6342 6341 6340 6338 6336 6335 6333 6333 6333
6340 6319 6322 6324 6326 6328 6330 6332 6333 6335 6336 6337 6339 6340 6341
6342 6343 6344 6344 6344 6344 6344 6343 6342 6341 6340 6339 6338 6337 6337
6340 6320 6322 6324 6327 6328 6330 6332 6333 6335 6336 6338 6339 6340 6341
6342 6343 6344 6345 6345 6345 6345 6345 6344 6343 6343 6342 6341 6340 6340
6340 6320 6322 6325 6327 6328 6330 6332 6333 6335 6336 6338 6339 6340 6342
6343 6344 6345 6346 6346 6347 6347 6346 6346 6346 6345 6344 6344 6343 6343
6340 6321 6323 6325 6326 6328 6330 6331 6333 6335 6336 6338 6339 6340 6342
6343 6344 6345 6346 6347 6348 6348 6348 6348 6347 6347 6347 6346 6346 6345
6340 6321 6323 6324 6326 6328 6329 6331 6332 6334 6336 6337 6339 6340 6342
6343 6344 6345 6347 6348 6349 6349 6349 6349 6349 6349 6348 6348 6348 6348
6340 6321 6322 6324 6325 6327 6328 6330 6331 6333 6335 6336 6338 6340 6341
6342 6344 6345 6347 6348 6350 6350 6350 6350 6350 6350 6350 6350 6350 6350
  1826.25        1        1.                                  T-1
      30.        1        1.                                  T-2
      30.        1        1.                                  T-3
      30.        1        1.                                  T-4
      30.        1        1.                                  T-4
```

stress periods

```
        0          0                 SS if ISS=1,    IBCFBD      BCF.AC1
 1 0
        0          1.                                 TRPY        L-1
        0        100.                                 DELR
        0        100.                                 DELC
       11        0.25  (30F2.0)                  11     SF1-1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

storage coef

```
       11          2.4  (25F3.0)                  8      HY-1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    1
  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    2
  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    3
  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    4
  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    5
  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    6
  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    7
  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    8
  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1    9
  1  1  1  1  1
  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2    10
  2  2  2  2  2
  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3    11
  3  3  3  3  3
  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4    12
  4  4  4  4  4
  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5    13
  5  5  5  5  4
  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6 10 10  6  6  6  6    14
```

Hydraulic Cond.

```
 6  6  6  5  4
 7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7   15
 7  7  6  5  4
 8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8   16
 8  7  6  5  4
 9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9   17
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9   18
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9   19
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9   20
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9   21
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9   22
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9   23
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9   24
 8  7  6  5  4
       0     620.                                BOT-1
```

10	0					DRN.AC1
10	row	col	Elev	Cond	Drains	T-1
1	3	16	625.0	5000.		
1	3	17	625.0	5000.		
1	4	12	625.0	5000.		
1	4	15	625.0	5000.		
1	4	16	625.0	5000.		
1	4	17	625.0	5000.		
1	5	12	625.0	5000.		
1	5	15	625.0	5000.		
1	5	16	625.0	5000.		
1	5	17	625.0	5000.		
-1					T-2	
-1					T-3	
-1					T-4	
-1					T-5	
-1					T-6	
-1					T-7	
-1					T-8	
-1					T-9	
-1					T-10	
-1					T-11	

Landfill Dewatering

52	0					RIV.AC1
52	Row	Col	Stage	Cond	RBOT	T-1
1	2	1	633.0	1500.	627.0	
1	2	2	633.0	1500.	627.0	
1	2	3	633.0	1500.	627.0	
1	2	4	633.0	1500.	627.0	
1	2	5	633.0	1500.	627.0	
1	2	6	633.0	1500.	627.0	
1	2	7	633.0	1500.	627.0	
1	2	8	633.0	1500.	627.0	
1	2	9	633.0	1500.	627.0	
1	2	10	633.0	1500.	627.0	
1	2	11	633.0	1500.	627.0	
1	2	12	633.0	1500.	627.0	
1	2	13	633.0	1500.	627.0	
1	2	14	630.0	1500.	627.0	
1	2	15	630.0	1500.	627.0	
1	2	16	630.0	1500.	627.0	
1	2	17	630.0	1500.	627.0	
1	2	18	630.0	1500.	627.0	
1	2	19	630.0	1500.	627.0	
1	2	20	630.0	1500.	627.0	
1	2	21	630.0	1500.	627.0	
1	2	22	630.0	1500.	627.0	
1	2	23	630.0	1500.	627.0	
1	2	24	630.0	1500.	627.0	
1	2	25	630.0	1500.	627.0	
1	2	26	630.0	1500.	627.0	
1	2	27	630.0	1500.	627.0	
1	2	28	630.0	1500.	627.0	
1	3	28	630.0	1500.	627.0	
1	4	28	630.0	1500.	627.0	
1	5	28	630.0	1500.	627.0	
1	6	28	630.1	1500.	627.0	
1	7	28	630.2	1500.	627.0	
1	8	28	630.3	1500.	627.0	
1	9	28	630.4	1500.	627.0	
1	10	28	630.5	1500.	627.0	
1	11	28	630.6	1500.	627.0	
1	12	28	630.7	1500.	627.0	
1	13	28	630.8	1500.	627.0	
1	14	28	630.9	1500.	627.0	
1	15	28	631.0	1500.	627.0	
~~1~~	~~15~~	~~29~~	631.5	1500.	627.5	
1	15	30	632.0	1500.	628.0	
1	8	16	631.0	500.	628.0	
1	9	16	631.0	500.	628.0	
1	10	16	631.0	500.	628.0	
1	11	16	631.0	500.	628.0	
1	12	15	632.0	500.	628.0	
1	12	14	632.0	500.	628.0	
1	13	13	632.0	500.	628.0	
1	13	12	632.0	500.	628.0	
1	13	11	632.0	500.	628.0	
-1						T-2
-1						T-3
-1						T-4
-1						T-5

102	0				GBH.AC1
102	Row	Col	Head	Cond	
1	24	1	634.0	25.	
1	24	2	634.0	25.	
1	24	3	634.0	25.	
1	24	4	634.0	25.	
1	24	5	634.0	25.	
1	24	6	634.0	25.	
1	24	7	634.0	25.	
1	24	8	634.0	25.	
1	24	9	634.0	25.	
1	24	10	634.0	25.	
1	24	11	634.0	25.	
1	24	12	634.0	25.	
1	24	13	634.0	25.	
1	24	14	634.0	25.	
1	24	15	634.1	25.	
1	24	16	634.2	25.	
1	24	17	634.4	25.	
1	24	18	634.5	25.	
1	24	19	634.7	25.	
1	24	20	634.8	25.	
1	24	21	635.0	25.	
1	24	22	635.0	25.	
1	24	23	635.0	25.	
1	24	24	635.0	25.	
1	24	25	635.0	25.	
1	24	26	635.0	25.	
1	24	27	635.0	25.	
1	24	28	635.0	25.	
1	24	29	635.0	25.	
1	24	30	635.0	25.	
1	1	1	634.0	25.	2 missing see RW
1	3	1	634.0	25.	
1	4	1	634.0	25.	
1	5	1	634.0	25.	
1	6	1	634.0	25.	
1	7	1	634.0	25.	
1	8	1	634.0	25.	
1	9	1	634.0	25.	
1	10	1	634.0	25.	
1	11	1	634.0	25.	
1	12	1	634.0	25.	
1	13	1	634.0	25.	
1	14	1	634.0	25.	
1	15	1	634.0	25.	
1	16	1	634.0	25.	
1	17	1	634.0	25.	
1	18	1	634.0	25.	
1	19	1	634.0	25.	
1	20	1	634.0	25.	
1	21	1	634.0	25.	
1	22	1	634.0	25.	
1	23	1	634.0	25.	
1	1	2	634.0	25.	
1	1	3	634.0	25.	
1	1	4	634.0	25.	
1	1	5	634.0	25.	

1	1	6	634.0	25.	
1	1	7	634.0	25.	
1	1	8	634.0	25.	
1	1	9	634.0	25.	
1	1	10	634.0	25.	
1	1	11	634.0	25.	
1	1	12	634.0	25.	
1	1	13	634.0	25.	
1	1	14	634.0	25.	
1	1	15	634.0	25.	
1	1	16	634.0	25.	
1	1	17	634.0	25.	
1	1	18	634.0	25.	
1	1	19	634.0	25.	
1	1	20	634.0	25.	
1	1	21	634.0	25.	
1	1	22	634.0	25.	
1	1	23	634.0	25.	
1	1	24	634.0	25.	
1	1	25	634.0	25.	
1	1	26	634.0	25.	
1	1	27	634.0	25.	
1	1	28	634.0	25.	
1	1	29	634.0	25.	
1	1	30	633.0	25.	
1	2	30	633.0	25.	
1	3	30	633.0	25.	
1	4	30	633.0	25.	
1	5	30	633.0	25.	
1	6	30	633.0	25.	
1	7	30	633.0	25.	
1	8	30	633.0	25.	
1	9	30	633.0	25.	
1	10	30	634.0	25.	
1	11	30	634.0	25.	
1	12	30	634.0	25.	
1	13	30	634.0	25.	
1	14	30	634.0	25.	15 missing
1	16	30	635.0	25.	
1	17	30	635.0	25.	
1	18	30	635.0	25.	
1	19	30	635.0	25.	
1	20	30	635.0	25.	
1	21	30	635.0	25.	
1	22	30	635.0	25.	
1	23	30	635.0	25.	
-1					T-2
-1					T-3
-1					T-4
-1					T-5
-1					T-6
-1					T-7
-1					T-8

```
         1         0                     NRCHOP,  IRCHCB          RCH.AC1
         1                               INRECH                       T-1
        18  .0013693 (30F2.0)                      11            6.0"/YEAR
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0.3.3.3.5.5.5.5.5.5.5.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0.3.3.3.3.5.5.5.5.5.5.5.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0.3.3.3.3.5.5.5.5.5.5.5.5.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0.3.3.3.3.5.5.5.5.5.5.5.5.5.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0.3.3.3.5.5.5.5.5.5.5.5.5.5.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0.3.3.3.5.5.5.5.5.5.5.5.5.5.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0.3.3.3.5.5.5.5.5.5.5.5.5.5.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0.3.3.5.5.5.5.5.5.5.5.5.5.5.5 0 0.3.3.3.3.3.3.3.3.3.3.3 0 0
 0.3.3.5.5.5.5.5.5.5.5.5.5.5.5 0 0.3 5 5 5 5 1 1 1.3.3.3 0 0
 0.3.3.5.5.5.5.5.5.5.5.5.5.5.5.3.3.3 2 2 2 2 2 1 1 1.3.3 0 0
 0.3.3.5.3.5.5.5.5.5.5.5 1 1 1 1.5 1 25050 2 2 2 5 1.3.3 0 0
 0.3.3.3.3.5.5.5.5.5.5.5 1 2 2 2 1 1 2 2 2 2 2 2 5 1.3.3.3 0
 0.3.3.3.3.5.5.5.5.5.5.5 1 2 2 2 1 1 1 1 1 1 1 1 1 1.3.3.3 0
 0.0.3.3.3.3.3.3.3.3.3.5 1 1 1 1 1 1 1 1 1 1 1 1 1 1.3.3.3 0
 0 0 0 0 0 0 0 0 0 0 0 0 0.5.5.5.5 1 1 1 1 1 1 1 1 1.3.3.3 0
 0 0 0 0 0 0 0 0 0 0 0 0 0.5.5.5.5 [illegible] 1 1 1 1 1 1 1 1.3.3.3 0
 0 0 0 0 0 0 0 0 0 0 0 0.5.5.5.5.5.3.3.3.3.3.3.3.3.3.3.3.3 0
 0 0 0 0 0 0 0 0 0 0 0 0.5.5.5.5.5.3.3.3.3.3.3.3.3.3.3.3.3 0
 0 0 0 0 0 0 0 0 0 0 0.5.5.5.5.5.5.3.3.3.3.3.3.3.3.3.3.3.3 0
 0 0 0 0 0 0 0 0 0 0 0.5.5.5.5.5.3.3.3.3.3.3.3.3.3.3.3.3 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
        -1                               INRECH                       T-2
        -1                               INRECH                       T-3
        -1                               INRECH                       T-4
        -1                               INRECH                       T-5
        -1                               INRECH                       T-6
        -1                               INRECH                       T-7
        -1                               INRECH                       T-8
        -1                               INRECH                       T-9
```

4

10

11

5

2=12 4

1=6 3

.5=3 2

.3=1.8 1

0=0

5=60 6

50=~~600~~ 300 7

50	10		
1.0	0.005	1	SIP.AC1

4	4	0	0	IHEDFM,IDDNFM,IHEDUN,IDDNUN	AC1
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1	0	1	0	hdpr,ddpr,hdsv,ddsv	L-1
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-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T3
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T4
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T5
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T6
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T7
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T8
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T9
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T10
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T11
-1	1	0	1	INCODE,IHDDFL,IBUDFL,ICBCFL	T12

INPUT FILES
FUTURE CONDITION GROUNDWATER FLOW SYSTEM

```
BAS.AC3 -- K x 1 (2.4), 6 in/yr precip, creek 630 ft, Leach ditch 632 ft
30 year simulation,  No leachate collection system, no firepond source
        1        24        30         1         4
 11  0  0 14  0  0 17 18 19  0  0 22  0  0  0  0  0  0  0  0  0 24  0  0
        0         0                                             IAPART,ISTRT
        1         1  (30I2)                     3               IBOUND-1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 1 1 1 1 1 1 1 1 1 1 2 1 1
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 1 1 1 1 1 1 1 1 1 1 1 2 1 1 2 2 2 1 1 1 1 1 1 1 1 1 1 2 1 1
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 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 1 1 1 1 1 1 2 1 1
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    630.5
        1         1  (15F5.1)                   4               IHEAD-1
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 6301 6302 6302 6301 6300 6300 6300 6300 6300 6300 6300 6300 6300 6301 6301
 6340 6301 6300 6300 6300 6300 6300 6300 6300 6295 6300 6304 6300 6300 6300
 6300 6300 6304 6304 6304 6304 6304 6304 6303 6303 6302 6301 6300 6301 6300
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 6300 6300 6307 6307 6307 6307 6307 6307 6306 6305 6304 6302 6300 6301 6300
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 6340 6309 6311 6313 6314 6314 6315 6315 6315 6315 6315 6315 6316 6317 6319
 6320 6321 6322 6322 6322 6321 6320 6318 6316 6313 6310 6306 6301 6303 6304
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 6324 6324 6325 6325 6325 6324 6323 6321 6318 6315 6311 6306 6301 6303 6305
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 6327 6327 6328 6328 6328 6327 6325 6323 6320 6317 6312 6307 6301 6304 6306
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 6330 6330 6331 6331 6331 6330 6328 6326 6323 6319 6314 6308 6301 6305 6307
 6340 6313 6316 6318 6320 6322 6324 6325 6326 6327 6328 6329 6330 6331 6332
 6332 6333 6334 6334 6334 6333 6331 6329 6326 6321 6316 6310 6301 6306 6308
```

6340	6314	6317	6320	6322	6324	6325	6327	6328	6329	6330	6331	6332	6333	6334
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6317	6320	6322	6324	6327	6328	6330	6332	6333	6335	6336	6338	6339	6340	6341
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6343	6344	6345	6346	6346	6347	6347	6346	6346	6346	6345	6344	6344	6343	6343
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6343	6344	6345	6346	6347	6348	6348	6348	6348	6347	6347	6347	6346	6346	6345
6319	6321	6323	6324	6326	6328	6329	6331	6332	6334	6336	6337	6339	6340	6342
6343	6344	6345	6347	6348	6349	6349	6349	6349	6349	6349	6348	6348	6348	6348
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6342	6344	6345	6347	6348	6350	6350	6350	6350	6350	6350	6350	6350	6350	6350
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1826.25			1		1.								T-2	

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        0       100.                                  DELR
        0       100.                                  DELC
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       11        2.4  (25F3.0)                   8      HY-1
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  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
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  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4
  4  4  4  4  4
  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
  5  5  5  5  4
  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6
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 8  8  8  8  8  8  8  8  8  8  8  8  8  6  8  8  8  8  8  8  8  8  8  8  8
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 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9
 8  7  6  5  4
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9
 8  7  6  5  4
       0     620.                          BOT-1
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52	0					RIV.AC3
52	Row	Col	Stage	Cond	RBOT	T-1
1	2	1	630.0	1500.	627.0	
1	2	2	630.0	1500.	627.0	
1	2	3	630.0	1500.	627.0	
1	2	4	630.0	1500.	627.0	
1	2	5	630.0	1500.	627.0	
1	2	6	630.0	1500.	627.0	
1	2	7	630.0	1500.	627.0	
1	2	8	630.0	1500.	627.0	
1	2	9	630.0	1500.	627.0	
1	2	10	630.0	1500.	627.0	
1	2	11	630.0	1500.	627.0	
1	2	12	630.0	1500.	627.0	
1	2	13	630.0	1500.	627.0	
1	2	14	630.0	1500.	627.0	
1	2	15	630.0	1500.	627.0	
1	2	16	630.0	1500.	627.0	
1	2	17	630.0	1500.	627.0	
1	2	18	630.0	1500.	627.0	
1	2	19	630.0	1500.	627.0	
1	2	20	630.0	1500.	627.0	
1	2	21	630.0	1500.	627.0	
1	2	22	630.0	1500.	627.0	
1	2	23	630.0	1500.	627.0	
1	2	24	630.0	1500.	627.0	
1	2	25	630.0	1500.	627.0	
1	2	26	630.0	1500.	627.0	
1	2	27	630.0	1500.	627.0	
1	2	28	630.0	1500.	627.0	
1	3	28	630.0	1500.	627.0	
1	4	28	630.0	1500.	627.0	
1	5	28	630.0	1500.	627.0	
1	6	28	630.1	1500.	627.0	
1	7	28	630.2	1500.	627.0	
1	8	28	630.3	1500.	627.0	
1	9	28	630.4	1500.	627.0	
1	10	28	630.5	1500.	627.0	
1	11	28	630.6	1500.	627.0	
1	12	28	630.7	1500.	627.0	
1	13	28	630.8	1500.	627.0	
1	14	28	630.9	1500.	627.0	
1	15	28	631.0	1500.	627.0	
1	15	29	631.5	1500.	627.5	
1	15	30	632.0	1500.	628.0	
1	8	16	631.0	500.	628.0	
1	9	16	631.0	500.	628.0	
1	10	16	631.0	500.	628.0	
1	11	16	631.0	500.	628.0	
1	12	15	632.0	500.	628.0	
1	12	14	632.0	500.	628.0	
1	13	13	632.0	500.	628.0	
1	13	12	632.0	500.	628.0	
1	13	11	632.0	500.	628.0	
-1						T-2
-1						T-3
-1						T-4
-1						T-5

102	0				6BH.AC1
102	Row	Col	Head	Cond	
1	24	1	634.0	25.	
1	24	2	634.0	25.	
1	24	3	634.0	25.	
1	24	4	634.0	25.	
1	24	5	634.0	25.	
1	24	6	634.0	25.	
1	24	7	634.0	25.	
1	24	8	634.0	25.	
1	24	9	634.0	25.	
1	24	10	634.0	25.	
1	24	11	634.0	25.	
1	24	12	634.0	25.	
1	24	13	634.8	25.	
1	24	14	634.0	25.	
1	24	15	634.1	25.	
1	24	16	634.2	25.	
1	24	17	634.4	25.	
1	24	18	634.5	25.	
1	24	19	634.7	25.	
1	24	20	634.8	25.	
1	24	21	635.0	25.	
1	24	22	635.0	25.	
1	24	23	635.0	25.	
1	24	24	635.0	25.	
1	24	25	635.0	25.	
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1	24	27	635.0	25.	
1	24	28	635.0	25.	
1	24	29	635.0	25.	
1	24	30	635.0	25.	
1	1	1	634.0	25.	
1	3	1	634.0	25.	
1	4	1	634.0	25.	
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1	6	1	634.0	25.	
1	7	1	634.0	25.	
1	8	1	634.0	25.	
1	9	1	634.0	25.	
1	10	1	634.0	25.	
1	11	1	634.0	25.	
1	12	1	634.0	25.	
1	13	1	634.0	25.	
1	14	1	634.0	25.	
1	15	1	634.0	25.	
1	16	1	634.0	25.	
1	17	1	634.0	25.	
1	18	1	634.0	25.	
1	19	1	634.0	25.	
1	20	1	634.0	25.	
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1	22	1	634.0	25.	
1	23	1	634.0	25.	
1	1	2	634.0	25.	
1	1	3	634.0	25.	
1	1	4	634.0	25.	
1	1	5	634.0	25.	

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1	1	11	634.0	25.	
1	1	12	634.0	25.	
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1	1	27	634.0	25.	
1	1	28	634.0	25.	
1	1	29	634.0	25.	
1	1	30	633.0	25.	
1	2	30	633.0	25.	
1	3	30	633.0	25.	
1	4	30	633.0	25.	
1	5	30	633.0	25.	
1	6	30	633.0	25.	
1	7	30	633.0	25.	
1	8	30	633.0	25.	
1	9	30	633.0	25.	
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1	13	30	634.0	25.	
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1	16	30	635.0	25.	
1	17	30	635.0	25.	
1	18	30	635.0	25.	
1	19	30	635.0	25.	
1	20	30	635.0	25.	
1	21	30	635.0	25.	
1	22	30	635.0	25.	
1	23	30	635.0	25.	
-1					T-2
-1					T-3
-1					T-4
-1					T-5
-1					T-6
-1					T-7
-1					T-8

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         1         0                    NRCHOP,  IRCHCB          RCH.AC3
         1                              INRECH                       T-1
        18  .0013689 (30F2.0)                    11          6.0"/YEAR
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        -1                              INRECH                       T-2
        -1                              INRECH                       T-3
        -1                              INRECH                       T-4
        -1                              INRECH                       T-5
        -1                              INRECH                       T-6
        -1                              INRECH                       T-7
        -1                              INRECH                       T-8
        -1                              INRECH                       T-9
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SIP.AC3

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1.0	0.005	1

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INPUT FILES

SOLUTE TRANSPORT SIMULATION FOR LANDFILL AREA

```
ACS Groundwater Transport Model, Simulating Griffith Municipal Landfill
30 year simulation --   5 ug/l Benzene at source
       1        24        30         1               ;NLAY,NROW,NCOL,NPER
DAY FT  UNDF                                         ;LUNIT,TUNIT,MUNIT
T T T T                                              ;ADV,DSP,SSM,RCT
 1                                                   ;LAYCON
       0      100.                                   ;DELR
       0      100.                                   ;DELC
       0      634.                                   ;HTOP
       0       14.                                   ;DZ-LAYER1
       0      0.25                                   ;POROSITY-LAYER1
       0         1                                        ;ICBUND-LAYER1
     100        5.  (30F2.0)               7              ;SCONC-LAYER1
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      0.00                                                            ;CINACT
         1         0         1         0         T                    ;IFMTCN,IFMTNP IFMTRF,IFMTDP,SAVUCN
         4                                                            ;NPRS
    365.25   3652.50   7305.00   10957.5
         4                                                            ;NOBS
         1         3         4                                        ;Layer, Row, Col
         1         6         4
         1         9         4
         1         8        10
         T                                                            ;CHKMAS
   10957.5        30        1.                                        ;PERLEN,NSTP,TSMULT
        0.     10000                                                  ;DT0,MXSTRN
```

```
       3      0.5    75000                                          |MIXELM,PERCEL,MXPART
       3      .50                                                   |ITRACK,WD
  1.e-5         0        0       10        2       30         1     |DCEPS,NPLANE,NPL,NPH,NPMIN,NPMAX,SRMULT
       1        0        8                                          |INTERP,NLSINK,NPSINK
     .01                                                            |DCHMOC
```

```
0        2.                                  ;AL-LAYER1, ENTERED AS A UNIFORM VALUE
0        .20                                 ;TRPT, ENTERED AS A UNIRON VALUE
0        .20                                 ;TRPV
0        0.                                  ;DMCOEF
```

```
 F F T F T T                          ;FWEL,FDRN,FRCH,FEVT,FRIV,FGHB
     1000                                                   ;MXSS
       -1                                                   ;INCRCH
        0                                                   ;NSS
```

```
      1         0                                    ;ISOTHM,IREACT
      0       1.8                                    ;RHOB, ENTERED AS A UNIFORM VALUE
      0      .204                                    ;SP1
      0        1.                                    ;SP2
```

Darcy's law, Q = -KiA was used to evaluate the groundwater flow (Q) in the vicinity of the Griffith Municipal Landfill. A mass balance method, Q_1 x $Conc_1$ = Q_2 x $Conc_2$, was used in conjunction with the groundwater flow and observed leachate quality, to evaluate the potential groundwater quality in the upper and lower aquifer in the vicinity of the landfill.

Four components were identified in the groundwater flow in the upper and lower aquifer in the vicinity of the landfill. They are shown on the attached block diagram.

Q1 Areal recharge across the landfill area through existing landfill cover/cap.

Q2 Horizontal groundwater flow in the upper aquifer beneath the landfill.

Q3 Vertical groundwater flow through the clay confining layer between the upper and lower aquifers.

Q4 Horizontal groundwater flow in the lower aquifer.

The variables and calculations for each of the four flow components are shown in the attached table. The assignment of values for each of the variables was based on field observations and data.

<u>SELECTION OF VARIABLES</u>
In accordance with Darcy's law Q = -KiA, the groundwater discharge (Q) in each flow component can be calculated from the field derived values for each of the variables, hydraulic conductivity (K), hydraulic gradient (i), and cross-sectional aquifer area (A). (The minus sign only indicates flow direction and therefore is not relevant to this analysis of flow volume.)

<u>Flow Component Q_1</u>
Q_1 represents the source of groundwater and leachate in the aquifer. Figure 4-21 shows that the landfill area of concern is approximately 1000 feet by 1000 feet, between the 634 contour lines in the northwest and southeast, and the 635 contour line in the northeast. The groundwater flow is toward the landfill de-watering area, shown by the closed 625-foot contour line. Landfill contaminants were not detected in monitoring wells MW-1 and MW-15, indicating that the groundwater discharge is toward the northwest. The numerical modeling of the Site with the U.S.G.S. Modflow model (Appendix Y) showed that groundwater flow in the upper aquifer would still be toward the west, toward the creek, even if the de-watering activities are ceased at the Site.

It is assumed that that no further covering or capping of the landfill is conducted. In this case, it is reasonable to assume that approximately 25 percent (1 foot) of the annual 48 inches of precipitation would infiltrate into the landfill to form groundwater and leachate. Assuming a 1000 by 1000 foot landfill area, this infiltration represents 1,000,000 cubic feet of water per year. Darcy's law can be inverted to test for reasonableness of this calculation.

The only unknown for the landfill is the K-value, so Darcy's law can be re-arranged in the form K = Q/iA. The hydraulic gradient from the center of the landfill (Figure 4-21) toward the west is 0.5 foot drop in 1000 feet (i = 0.0005). The cross-sectional area, A = 14 x 1000 = 14,000 ft^2. (The bottom of the upper aquifer is at elevation of 620 feet msl and the water table is approximately 634 feet msl). Solving for K, yields a value of 0.27 feet/min ($1.3x10^{-1}$ cm/sec), which is not an unreasonable K-value for unconsolidated fill and trash.

Flow Component Q_2
Groundwater flow component Q_2 is equal to component Q_1. The discharge is currently to the landfill de-watering area. If de-watering is discontinued, it would be to the creek which now flows past the west side of the landfill.

Flow Component Q_3
The hydraulic conductivity of the clay confining layer is known from laboratory tests on several samples collected during the field investigation. The results are summarized on Table 4-7. The average value is K = $4.8x10^{-8}$ cm/sec. The vertical hydraulic gradient across the clay confining layer varies somewhat across the Site, but generally is in the range of unity (i = 1) (see Table 4-6). The seepage would occur across the landfill area of concern, 1000 by 1000 feet, so A = 1,000,000 square feet.

Flow Component Q_4
Groundwater flow in the lower aquifer can be calculated from the field measurements of hydraulic conductivity and hydraulic gradient. Slug tests at four lower aquifer monitoring wells indicated an average hydraulic conductivity of K = $4.4x10^{-2}$ ft/min for upper part of the lower aquifer (Section 4.5.3.3). Water levels were measured at the lower aquifer monitoring wells on three separate dates and the hydraulic conductivity was consistently i = 0.00063 (Figures 4-22, 4-23, and 4-23A). The width of the affected aquifer was assumed to be 1000 feet. It was assumed that the leakage through the clay confining layer would diffuse/disperse into the upper 20 feet of the lower aquifer. Therefore, A = 1000 x 20 feet = 20,000 feet.

The calculations of groundwater flow are summarized on the first page of the attached table.

POTENTIAL CONTAMINANT LOADING

The landfill leachate is the source of potential contamination. Several VOCs were detected in the leachate sampling results. Benzene, detected in each of the leachate wells, is the compound of potential concern. The results are tabulated in Appendices Q-1 and R-1. It is reasonable to assume that the impact to the upper and lower aquifer would result from the average leachate concentration detected in the landfill, which is 4.5 ug/L for benzene.

This concentration of benzene was used with the groundwater flow volumes to calculate the contaminant loading to the upper aquifer, surface water, and lower aquifer in the vicinity of the landfill. The results are summarized on the second page of the attached table.

Mass balance calculation of potential impacts to upper and lower aquifer from Griffith Municipal Landfill Leachate.

Q1 = Areal Recharge across landfill area (annual infiltrating precipitation)
Q2 = Upper Aquifer horizontal Discharge to de-watering area
Q3 = Leakage from upper to lower Aquifer
Q4 = Lower Aquifer Discharge to the north.

Q1 = Landfill Area x Infiltrating Precipitation

Area =	1,000,000	sq ft	(1000 x 1000 ft)
Infiltration =	1	ft/yr	
Q1 =	1,000,000	cu ft/yr	

Q2 = KiA   Q2 = Q1
K = Q2/iA

Q2 =	1,000,000	cu ft/yr	
i =	0.0005	ft/ft	
A =	14,000	sq. ft	(14 x 1000 ft)
K =	143,000	ft/yr	
	2.7E-1	ft/min	

Q3 = K'iA   K' = K/thickness   Thickness = 10 ft

K' =	4.8E-8	cm/sec	
	5.0E-2	ft/yr	
i =	1	ft/ft	
A =	1,000,000	sq ft	(1000 x 1000 ft)
Q3 =	50,000	cu ft/yr	

Q4 = KiA

K =	4.40E-02	ft/min	
	23,000	ft/yr	
i =	0.00063	ft/ft	
A =	20,000	ft	(20 x 1000 ft)
Q4 =	290,000	cu ft/yr	

Mass Balance

Upper Aquifer

At the present time, Q1, the groundwater leachate flowing beneath the landfill, discharges to the landfill de-watering area. At the present time, Q2 is the discharge into the landfill de-watering area. As such it is disposed of by the City of Griffith and not released to the environment.

It cannot be assumed that landfill de-watering will continue indefinitely into the future. Numerical modeling of the upper aquifer shows that if de-water is discontinued, the groundwater/leachate flowing from the landfill (Q1) will discharge exclusively to the creek located to the west of the current de-watering area. will discharge to the creek which is currently to the west of the landfill de-watering area.

In the future, it can be assumed that Q2, dicharge along the creek will be equal from both sides of the creek. Therefore, Q1 will be equal to one-half of Q2. This does not consider further dilution which would occur by the water already flowing down the stream from upstream.

Mass Balance Calculation

Q1 x Conc1 = Q2 x Conc2

Conc2 = (Q1 x Conc1)/Q2

Q1	=	1,000,000 cu ft/yr
Conc1	=	4.5 ug/L
Q2 = 2*Q1	=	2,000,000 cu ft/yr
Conc2	=	2.3 ug/L

Leachate Analytical Results

Leachate Well	Benzene conc.	
LW-1	5.0	ug/l
LW-2	2.0	ug/l
LW-3	5.0	ug/l
LW-4	6.0	ug/l
Average:	**4.5**	**ug/l**

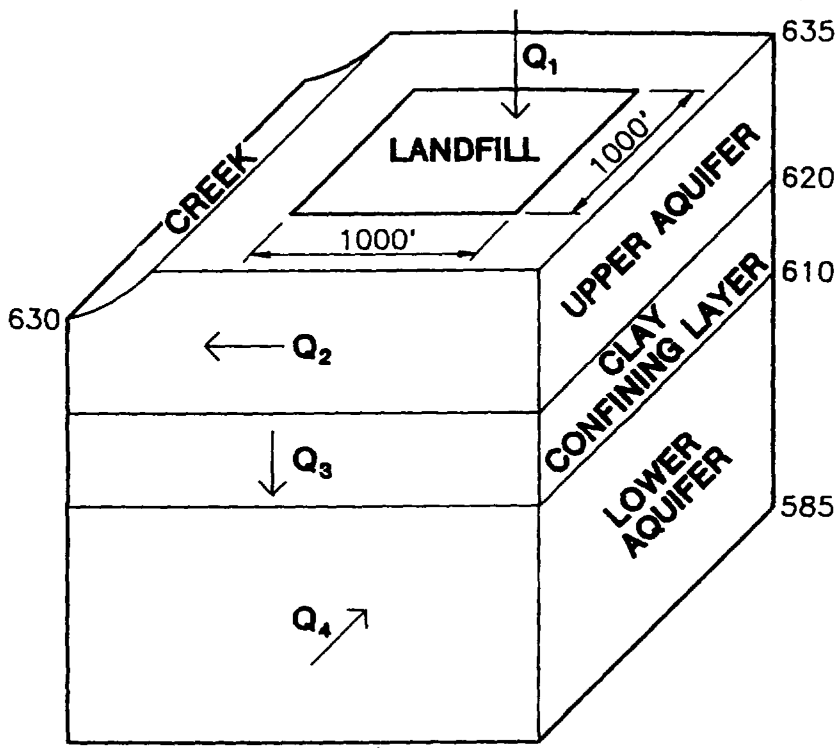
Lower Aquifer

Q3 x Conc3 = Q4 x Conc4

Conc4 = (Q3 x Conc3)/Q4

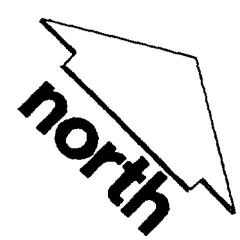
Q3	=	50,000 cu ft/yr
Conc3	=	4.5 ug/L
Q4	=	290000 cu ft/yr
Conc4	=	0.78 ug/L

Drafting Standards
Lead Professional
Section
PM
Division
Other



LEGEND

Q_1 = INFILTRATION
Q_2 = UPPER AQUIFER DISCHARGE
Q_3 = PERCOLATION THROUGH CONFINING LAYER
Q_4 = LOWER AQUIFER DISCHARGE
635 ELEVATION (M.S.L. IN FEET)



NOT TO SCALE

WARZYN	INPUTS FOR GROUNDWATER MODEL	Drawn TPB	Checked	App'd.
	REMEDIAL INVESTIGATION AMERICAN CHEMICAL SERVICES NPL SITE GRIFFITH, INDIANA	Revisions	Date 9/17/91
			60251 **A23**